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(54) **A cross-connect device and a method for switching based on space switching and grouping of channels**

(57) The present invention provides a cross-connect switching device (100) and a method of cross-connect switching of $N_f * N_1$ channels to one of a plurality of output lines (201, 202) of the switching device, $N_f * N_1$ being equal or greater than four. The device and method includes three basic elements:

1) a partial demultiplexer (20, 21))for partially demultiplexing the channels on its input lines (111, 112) into groups of channels and individual channels;
2) a space switch (18) for switching groups of channels en bloc; and
3) a combiner unit (22) for combining individual channels onto one of the output lines (201 202) of the cross-connect switching device (100).

The cross-connect switching device according to the present invention may be combined with similar or dissimilar switching devices to form a larger switching device.

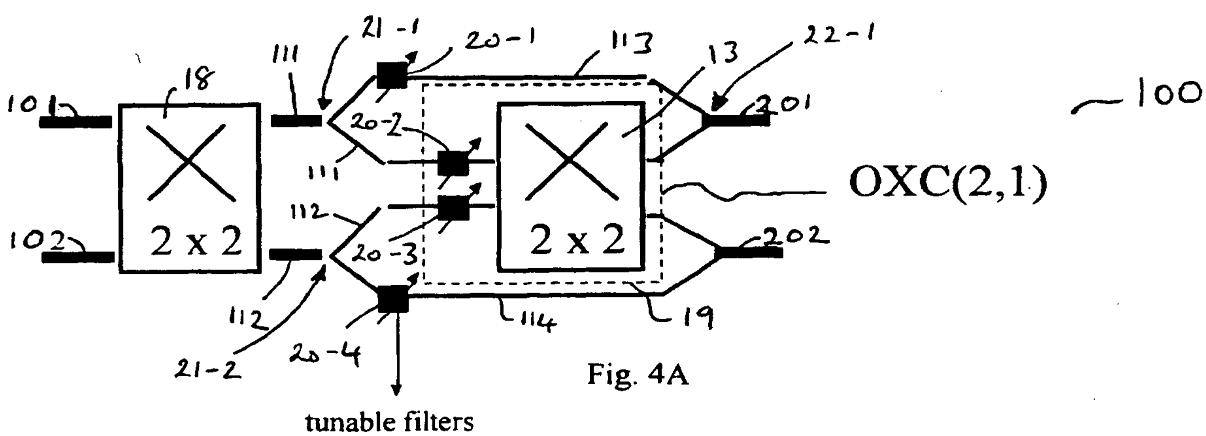

Fig. 4A

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Description

FIELD OF THE INVENTION

[0001] The present invention is a general cross-connect switching device and a general switching method for the cross-connecting of an arbitrary number of communication lines, e.g. optical fibres, carrying an arbitrary number of channels.

TECHNICAL BACKGROUND

[0002] In Wavelength Division Multiplexing (WDM) optical communication C. A. Brackett, A. S. Acampora, J. Sweitzer, G. Tangoman, M. T. Smith, W. Lennon, K. Wang, R. H. Hobbs, "A Scalable Multiwavelength Multihop Optical Network: A Proposal for Research on All-Optical Networks" IEEE Journ. Lightw. Techn., Vol. 11, pp. 736-753, 1993, several signals are transmitted simultaneously over a single optical fibre by multiplexing the different signals on different carrier wavelengths.

[0003] WDM networks consist of different WDM optical connections, each of which consists of several fibres carrying WDM signals, and of optical cross-connects to switch between the different links. An example is schematically shown in Fig. 1. The lines all represent optical waveguides, often fibres, with WDM signals. The optical cross-connects (OXC) preferably have the following functionality:

- individual channels from each fibre can be dropped (for use in a local access network e.g.),
- individual channels (coming from the local access network) can be added to each fibre,
- individual channels from each fibre can be switched to any other fibre.

[0004] Different wavelength channels from one fibre may be switched to different output fibres. In some cases, one also requires that the individual channels can be converted in wavelength so that wavelength contention can be avoided if two channels with equal wavelength have to be switched to the same output fibre.

[0005] A typical architecture of an optical cross-connect, with Nf incoming fibres and N_f outgoing fibres, is depicted in Figs. 2A and B. Reference is made to M. S. Borella et al., "Optical Components for WDM Lightwave Networks", Proc. of the IEEE, Vol. 85, pp. 1274-1307, 1997, E. Iannone, R. Sabella, "Optical Path Technologies: A Comparison Among Different Cross-Connect Architectures", IEEE Journ. Lightw. Techn., Vol. 14, pp. 2184-2196, 1996 and J. Zhou et al., "Crosstalk in Multiwavelength Optical Cross-Connect Networks", IEEE Journ. Lightw. Techn., Vol. 14, pp. 1423-1435, 1996. The cross-connecting functionality is achieved by first demultiplexing signals on the incoming fibres into the individual channels, by subsequently space switching all the individual wavelength channels, possibly followed by wavelength conversion (Fig. 2B) and by finally multiplexing or recombining the switched individual channels. Different variations of this architecture have been proposed in the literature. However, they all more or less are based on the same principle and they all require an N-dimensional space switch, with N being the product of the number of incoming and outgoing fibres and the number of wavelength channels per fibre. For example, in Patent Application JP9224268 a cross-connect device is presented wherein first all fibres are demultiplexed before switching.

[0006] In most of the optical cross-connects of the type shown in Fig. 2, the optical filters can have a fixed wavelength dependence. There are then N_f x N_l such filters, with N_f being the number of input and output fibres and N_l the number of wavelength channels per fibre. Furthermore, if full connectivity is required (that means if it must be possible to connect 2 channels with equal wavelength but from different input fibres to the same output fibre, making use of wavelength conversion), a total of $N_f(N_f-1)x(N_l)^2/2$ elementary 2x2-switches are required. An alternative, however, is to use tuneable optical filters (which can filter any of the wavelength channels), in which case only $N_f(N_f-1)x(N_l)/2$ elementary 2x2-switches are required. If no wavelength conversion is used and only connections between the different fibres are needed for the individual channels (meaning that for each individual channel at the input a connection with all output fibres is necessary), then $N_f(N_f-1)x(N_l)/2$ elementary 2x2-switches are required.

[0007] The main drawback of conventional cross-connect devices is the number of components (filters, switches) needed.

[0008] A cross-connect device with N_f input fibres and N_f output fibres and with N_f an even number can be build as a combination of smaller cross-connects with 2 input and 2 output fibres. This is illustrated in Fig. 3 for the case of 4 input and 4 output fibres. In this figure, OXC-$(2,2^M)$ stands for an optical cross-connect with 2 input and 2 output fibres, with each fibre carrying 2^M wavelength channels. The notation 2x2 OXC represents an optical cross-connect device with 2 input and 2 output fibres.

[0009] It should be emphasised that the discussion above is not limited to optical systems. Switching in electrical communication systems exploiting frequency division multiplexing (FDM) shows the same characteristics. Frequency channels in electrical communications are equivalent in this respect to wavelength channels in optical systems.

AIM OF THE INVENTION

[0010] The object of the invention is to provide cross-connect devices comprising less components than the devices known from the state of the art.

[0011] Another object of the present invention is to provide a method of cross-connecting which allows im-

plementation of cross-connect devices having less components.

[0012] Another object of the present invention is to provide a cross-connect switch and a method of operating the same which provides full connectivity while reducing the cost of the device.

SUMMARY OF THE INVENTION

[0013] In a first embodiment of the invention a cross-connect switching device with N_f input fibres and N_f output fibres, each fibre carrying N_l channels is provided. The input fibres carry the same amount of channels N_l, thus the channels are equally distributed over the input fibres. The output fibres carry the same amount of channels as the input fibres. An aspect of the cross-connect switching device according to the first embodiment is that it comprises a switching unit for switching an amount of channels, these channels being a subset of the channels to be switched by the cross-connect switching device. An aspect of this first embodiment is that the switching unit may have the same structure as the cross-connect switching device itself.

[0014] The cross-connect switching device according to this embodiment is able to switch all the channels, i. e. the amount of channels per input fibre multiplied by the amount of input fibres, thus N_f * N_l With switching is meant that any one input channel can be connected to any one of the output fibres of device. Each of the output fibres has a fixed amount of channels and unless there is wavelength conversion foreseen in the device only input channels with different wavelengths can be connected to the same output fibre.

[0015] The cross-connect switching device according to this embodiment may comprise the following components: (1) a space switch with N_f input fibres and N_f output fibres, (2) N_f splitters, each having one input fibre and a plurality of output fibres, (3) a switching unit with N_f input fibres and N_f output fibres able to switch an amount of channels strictly smaller than N_f*N_l, (4) a plurality of filters, each having one input fibre and one output fibre, (5) N_f combiners, each having a plurality of input fibres and one output fibre.

[0016] The inputs of the cross-connect switching device according to this embodiment are the inputs to the switch while the outputs of the device are the outputs of the combiners. Moreover the splitters are applied to the output fibres of the switch, meaning that to each of the outputs a splitter is connected. At least part of the output fibres of the switch are connected to filters. The switching unit can switch less channels than the cross-connect device itself and moreover the channels, switched by the switching unit, are a subset of the channels on the outputs of the switch. The channels of the switch are connected to the inputs of the switching unit via the splitters.

[0017] Hence, the present invention includes a cross-connect switching device with N_f input lines and N_f output lines and N_l channels per line and being able to switch any of the N_f * N_l input channels to one of the output lines. N_f * N_l being equal or greater than four, the channels being equally distributed over the input lines. comprising:

a switch being operatively connected to at least some of the input lines of the cross-connect switching device and being adapted to switch at least one channel group on one input line of the switch en bloc to an output line of the switch, a channel group including a plurality of channels up to a maximum of N_l channels;
a partial demultiplexer operatively connected to the switch for selecting at least one individual channel from at least one channel group; and
a combiner unit for combining the selected individual channel onto an output line.

[0018] The present invention also includes a cross-connect switching device with N_f input lines and N_f output lines and N_l channels per line, and being able to switch any of the N_f * N_l input channels to one of the output lines, N_f * N_l being equal or greater than four, the channels being equally distributed over the input lines, comprising:

a partial demultiplexer operatively connected to at least some of the input lines of the cross-connect switching device for partial demultiplexing the channels on an input line of the partial demultiplexer into at least a group of channels and an individual channel, a channel group including a plurality of channels up to a maximum of N_l channels;
a switch operatively connected to the output side of the partial demultiplexer, the switch being adapted to switch the at least one channel group en bloc to an output line of the switch; and
a combiner unit for combining the individual channel onto an output line.

[0019] The switching operation may include progressive serial space switching and the switch may include a series of space switches. Each space switch may be associated with a partial demultiplexer so that at each stage of the series, a group of channels is switched en bloc towards the relevant output fibre and certain of the channels of the group are demultiplexed, i.e selected from the group and transmitted towards the relevant output fibre.

[0020] Alternatively, the channel groups may first be formed by demultiplexing all the input channels and regrouping these channels into groups which may include a single channel or a plurlity of channels. The single channels and groups may then be switched en bloc towards the relevant output line using parallely arranged space switches. Finally, the switched groups and single channels are combined onto the output channels. To

avoid wavelength conflicts, the channels may be wavelength converted in wavelength converters, one per channel after the demultiplexing step.

[0021] The present invention includes a cross-connect switching device with N_f input fibres and N_f output fibres, being able to switch $N_f * N_l$ channels, $N_f * N_l$ being equal or greater than four, the channels being equally distributed over the input fibres, comprising:

a switch with N_f input fibres and N_f output fibres, the input fibres of the switch being the input fibres of the cross-connect switching device, the switch switching for each of the input fibres of the switch all channels towards one of the output fibres of the switch;
N_f splitters, each having one input fibre and a plurality of output fibres, the input fibre being one of the output fibres of the switch;
a switching unit with N_f input fibres and N_f output fibres, being able to switch a first number of channels, the first number being strictly smaller than $N_f * N_l$, the first number of channels being a subset of the channels on the output fibres of the switch;
a plurality of filters, each having one input fibre and one output fibre, part of the filters being applied to part of the plurality of output fibres of the splitters; and
a plurality of combiners, each having a plurality of input fibres and one output fibre, the output fibres of the combiners being the output fibres of the cross-connect device, each of the combiners combining the channels on a subset of the output fibres of the splitters onto one of the output fibres of the component.

[0022] The switching unit may also de denoted as a selecting and switching device. The selecting and switching device switches a subset of the channels on the outputs of the previous switch. In between this switch and the selecting and switching device a splitter is placed. The inputs of the selecting and switching device carry may all channels but the selecting and switching device can only switch a subset of these channels. Hence, this device includes a selecting means for selecting the channels that are to be switched. Note also that although combiners combine subsets of the outputs of the splitters, filters can be placed in between.

[0023] An aspect of this first embodiment of the invention is that there is a maximal amount of channels D to be split off per fibre. The maximal amount D equals the first integer larger than or equal to $[N_l /2 (N_f -1)]$ with N_l the amount of channels per fibre and N_f the amount of fibres. The designer can choose to split off a number of channels E, where E is at least one channel per fibre and maximally D channels per fibre. The amount of channels that remain to be switched by the switching unit is $N_f *(N_l -E)$.

[0024] An aspect of this first embodiment are the connections made between the components of the device: (1) each of the output fibres of the switch are connected to one of the input fibres of the splitters, (2) each of the input fibres of the switching unit are connected to one of the output fibres of one of the splitters, whereby the input fibres of the switching unit are not connected to the same splitter, (3) each of the input fibres of the filters are connected to one of the output fibres of one of the splitters, (4) each of the output fibres of the switching unit are connected to one of the input fibres of the combiners, whereby the output fibres of the switching unit are not connected to the same combiner, (5) each of the output fibres of the filters are connected to one of the input fibres of the combiners.

[0025] By connection between two components is meant that one side of a connection is attached to the input fibre of one component and the other side of the connection is attached to the output fibre of a second component. An input or an output fibre can only be connected once. Although the connection pattern described above incorporates various connection possibilities, the condition of only connecting once must always be satisfied. The fibre for connecting an input fibre with an output fibre can also contain an optical amplifier.

[0026] An aspect of this first embodiment is that the cross-connect switching device is to be able to switch 2^N+2*M channels with N an integer strictly greater than 1, 2*M an integer larger or equal to zero and strictly smaller than 2^N, with M an integer. The factor 2 is due to the fact that two input fibres are considered. The amount of channels per fibre can be a power of two (2^(N-1) with M=0) or any positive integer number (2^(N-1) +M). The minimal amount of channels to be switched with said device is 4.

[0027] The cross-connect switching device according to the invention may be characterized by a few numbers. A first number A is defined as the largest integer smaller than 2^(N-2)+M/2. A second number B is defined as an integer larger or equal to said first number A and strictly smaller than 2^(N-1)+M. A third number C is defined as the difference between 2^(N-1)+M and said second number B. Note that the selection of the second number B results in some design freedom. The device will be constructed such that it comprises of some standard components (switches, filters, splitters and combiners) and another component for switching channels. The switching unit also has two input fibres and two output fibres. The first number A depicts the lower bound for the amount of channels carried by the input fibres of the switching unit. Note that the first number A equals the amount of channels to be switched by the architecture under construction divided by 4. This factor 4 is due to the fact that the channels per input fibre are considered (first division by two) and that the input fibres of the switching unit are expected to have half as many channels to be switched (second division by two). Naturally the amount of channels must be an integer, which explains the additional constraint in the definition of the first number A. Note that the switching unit can be of a

lower complexity as only half as much channels must be switched. The amount of channels to be actually switched by the switching unit is depicted by the second number B which is lower bounded (equal or larger than) by the first number A and upper bounded (strictly smaller than) by the amount of channels, carried by the amount of channels of the input fibres of the device under construction (all the channels divided by two). The condition strictly smaller than is trivial as the component must be less complex than the device under construction.

[0028] An aspect of this first embodiment is that the splitters each have one input fibre and an amount of C+1 output fibres, the switching unit is able to switch 2*B channels, the cross-connect switching device has 2*C filters, each having one input fibre and one output fibre, and the two combiners each have C+1 input fibres and one output fibre.

[0029] In the above device, filters with one input fibre and one output fibre are considered. In practice filters can have more than one output fibre, e.g. one output fibre may contain the selected channel while another output fibre contains the complement of this channel. Such filters can also be used in the device defined above. The single output fibre of the filter is then the output fibre containing the selected channel.

[0030] A further aspect of this embodiment is that the switching unit in the cross-connect switching device is constructed in the same way as the device itself but designed to switch less channels per fibre. The number and type of components used to construct the switching unit in this way is adapted to the number of channels that are to be switched. This use of a further smaller cross-connect switching device within a cross-connect switching device is described a progressive serial switching in accordance with the present invention. In particular where the first switch is a space switch, this construction principle for a cross-connect switching device in accordance with the present invention will be called progressive serial space switching. Progressive serial space switching can be repeated for all the switching units in the design until a final switching unit is used to terminate the cascade, this last switching unit being able to switch a predetermined number of channels.

[0031] Note that recursively applying the same design results in a sequence of components of a first kind. The component of a second kind, which can switch a predetermined amount of channels, can then be a full-wired component. The predetermined amount of channels is at least equal to N_f or thus 1 channel per fibre.

[0032] In summary this aspect of the first embodiment can be stated as follows: The cross-connect switching device cited above, where the switching unit is further a part of a sequence of serially connected switching units of a first kind, the series being terminated by a switching unit of a second kind which is able to switch a predetermined amount of channels, the amount being an even integer strictly greater than N_f. The switching units can also be denoted selecting and switching devices.

[0033] Note that the filters used in this embodiment of the invention can be either tuneable or fixed The filters can also be combination of a filter and a wavelength converter. Moreover. it can be that part of the filters are combinations of a filter and a wavelength converter and another part just tuneable filters.

[0034] A second embodiment of the invention includes a method for switching N_f * N_l channels, being equally distributed over N_f input lines, to N_f * N_l channels, equally distributed over N_f output lines, there being N_l channels per line, the method comprising the step of using a combination of the following steps:

a) performing at least one switching operation in which at least one channel group is switched en bloc towards one of the output lines, a channel group including a plurality of channels up to a maximum of N_l channels;

b) partially demultiplexing to select at least one individual channel from at least one group, and

c) combining the selected individual channel onto an output line.

[0035] The second embodiment also includes a method for switching N_f*N_l channels, being equally distributed over N_f input lines, there being N_f * N_l channels equally distributed over N_f output lines, the method comprising the step of using a combination of the following steps:

a) partially demultiplexing the channels on an input line into at least one individual channel and at least one group of channels, a channel group including a plurality of channels up to a maximum of N_l channels;

b) performing at least one switching operation in which the at least one channel group is switched en bloc towards one of the output lines; and

c) combining the at least one individual channel onto an output line.

[0036] The method can for instance be implemented with the device described in the first embodiment of the invention. An aspect of the second embodiment is that the group switching operation includes progressive serial space switching. An alternative aspect of the second embodiment is that the group switching includes parallel space switching.

[0037] In an aspect of the second embodiment of the present invention a method for switching N_f * N_l channels being equally distributed over N_f input fibres to N_f * N_l channels being equally distributed over N_f output fibres is provided which comprises a finite sequence of space switching steps and thereafter a switching and selecting step, for switching an amount of channels equal to N_f multiplied with a number strictly less than N_l. With 'a space switching step' is meant that the channels carried by an input fibre used in the step are all switched

to the same output fibre, used in the step. With a selecting and switching step' is meant that in the step from all fibres used as input in the step, channels are selected, and the selected channels can be switched to any of the output fibres, used in the step. Note that a space switching step can be performed by a switch while a selecting and switching step can be performed by a selecting and switching device.

[0038] A third embodiment of the invention is to present a cross-connect switching device of a first kind having N_f input fibres and N_f output fibres. The input fibres each carry the same amount of channels N_l. Also the output fibres each carry N_l channels.

[0039] The cross-connect switching device of a first kind comprises of a plurality of cross-connect switching devices of a second kind, each of the cross-connect switching devices of a second kind having a number of input fibres and output fibres strictly less than the cross-connect switching device of a first kind. Note that each of the cross-connect switching devices of a second kind can have a different amount of input/output fibres. Examples of such cross-connect devices are depicted in Fig. 3 (cross-connect device of a first kind with 4 input fibres and 4 output fibres comprising of cross-connect devices of a second kind with 2 input fibres and 2 output fibres and Fig. 13 (cross-connect device of a first kind with 5 input fibres and 5 output fibres comprising cross-connect devices of a second kind with different amount of input/output fibres, more in particular one with 2 input and 2 output fibres, one with 3 input and 3 output fibres and two with 4 input and 4 output fibres).

[0040] At least one of the cross-connect switching devices of a second kind may be constructed by using the progressive serial space switching method described above. Thus at least one of the cross-connect devices of a second kind at least comprises a plurality of switches and a selecting and switching unit.

[0041] The selecting and switching unit has an number of input fibres and output fibres equal to the number of input fibres and output fibres of the cross-connect switching device of a second kind to which the selecting and switching unit is a part and the selecting and switching unit, being able to switch an amount of channels equal to the amount of input fibres of the selecting and switching unit multiplied with a number strictly less than N_l. Note that the amount of switches and the amount of channels being switched by the selecting and switching unit can differ in each of the cross-connect devices of a second kind.

[0042] The cross-connect devices of a second kind can further comprise filters for selecting channels, splitters for duplicating channels on filters and combiners for combining or multiplexing the switched and/or selected channels onto output fibres.

[0043] In an aspect of this third embodiment each of the input fibres of the cross-connect switching device of a first kind are routed through at least one of the cross-connect switching devices of a second kind. Indeed when full connectivity is required one must have the ability to switch each channel of a certain input fibre to any one output fibre. With routing of the fibre is meant that when the cross-connect devices of a second kind are all connected, from each input fibre of the cross-connect device of a first kind a path to any output fibres of the cross-connect device of a first kind must exist via one of the switching devices of a second kind. With connecting cross-connect devices of a second kind is meant that all input fibres of each of the devices of a second kind are connected to an output of one of the devices of a second kind or is defined to be the input of the device of a first kind, and all output fibres of each of the devices of a second kind are connected to an input fibre of one of the devices of a second kind or is defined to be the output of the device of a first kind.

BRIEF DESCRIPTION OF THE FIGURES

[0044] Fig. 1 is a schematic representation of a cross-connected WDM optical network.

[0045] Fig. 2 shows a typical architecture of a conventional optical cross-connect: Fig. 2A without wavelength conversion and Fig. 2B with wavelength conversion.

[0046] Fig. 3 shows a conventional optical cross-connect with 4 input and 4 output fibres build as a combination of 6 optical cross-connects with 2 input and 2 output fibres.

[0047] Fig. 4 is a schematic representation of an optical cross-connect switching device for 2 input and 2 output fibres and 2 channels per fibre in accordance with an embodiment of the present invention.

[0048] Fig. 5 shows a cross-connect switching device in accordance with another embodiment of the present invention: in Fig. 4A with 4 and in Fig. 4B with 8 channels per fibre whereby OXC (2,L) stands for an optical cross-connect with 2 input and 2 output fibres each carrying L wavelength channels.

[0049] Fig. 6 shows schematically a further cross-connect switching device in accordance with an embodiment of the present invention which demonstrates a modular implementation of the cross-connect of Fig. 4B.

[0050] Figs. 7A and B show schematic representations of optical cross-connect devices in accordance with further embodiments of the present invention with wavelength conversion.

[0051] Fig. 8 shows schematically an optical cross-connect switching device in accordance with another embodiment of the present invention for 2 input and output fibres carrying each 4 channels using tuneable optical add drop multiplexers.

[0052] Fig. 9 shows further cross-connect switching devices in accordance with further embodiments of the present invention: in Fig. 9A for 4 channels per fibre and in Fig. 9B for 7 channels per fibre.

[0053] Fig. 10 is a schematic representation of a cross-connect switching device in accordance with a further embodiment of the present invention having

fixed wavelength filters and prior wavelength conversion.

[0054] Fig. 11 is a schematic representation of a cross-connect switching device in accordance with a further embodiment of the present invention.

[0055] Fig. 12 is a schematic representation of a cross-connect switching device with Nf input and output fibres in accordance with an embodiment of the present invention.

[0056] Fig. 13 is a schematic representation of a cross-connect switching device in accordance with an embodiment of the present invention with Nf input and output fibres build up from a number of cross-connect devices with less input and output fibres.

[0057] Fig. 14 shows equivalent representations of splitters and combiners as used in accordance with the present invention.

[0058] Fig. 15 is a schematic representation of a further embodiment of a cross-connect switching device in accordance of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0059] The present invention will be described with reference to certain embodiments and to certain drawings but the present invention is not limited thereto but only by the claims. Further, the present invention will be described mainly with reference to optical cross-connect devices but the present invention is not limited thereto but may find general use in a cross-connect device and in a switching method for cross-connecting of an arbitrary number of input communication lines each carrying an arbitrary number of channels. For example, the present invention may find advantageous use in a cross-connect for cable communication lines, e.g. coax cables, or for hydraulic logic circuits. Further, reference will be made to tuneable filters and to switches. The cross-connect switching devices in accordance with any embodiment of the present invention may include the necessary devices for selectably changing the tuning of the tuneable filters or for selectably activating switching of the switches.

[0060] In the description of the invention and in the claims the word "line" is used as general definition for transmission media such as an optical fibre or fibres or other waveguides for optical communication, or electrical cables such as coax cables for electrical communication. A channel is defined in accordance with CCITT as an identified portion of an interface. A channel is generally defined in terms of its transmission support and not by the use of the information carried. The most elemental form of channel is the lowest unit of transmission support which is capable of transmitting at least a part of a communication between parts of a telecommunications network. Channels may be organised in a hierarchy, e.g. channels may be multiplexed into a time division multiplexed system so that there are several elemental channels being carried in a time spaced way on a channel one level higher in the hierarchy. In accordance with the present invention various types of channels are described. A high level communication channel may transmit many different communications each of which is carried on its own channel. To provide separation and isolation (sometimes known as orthogonality) between concurrent communications, various methods are used. A time division channel is a transmission support unit which is isolated from other such units which might interfere with it by the individual communications being isolated in time, e.g. each user obtains a time slot in a frame. A coded channel is a transmission support unit which is isolated from other such units which might interfere with it by being coded with a special code. An example of such a channel is a user channel in a direct sequence spread spectrum system, e.g. with Code Division Multiple Access (CDMA). A frequency or wavelength channel is a transmission support unit which is isolated from other such units which might interfere with it by being confined to a specific frequency or frequency band (wavelength or wavelength band). Along one frequency channel, several orthogonal communications may be sent, for instance, several coded channels or several time division channels may be operated within a frequency channel. In more complex systems, a hierarchical channel organisation may include a plurality of frequency channels, each frequency channel supporting several time division channels, each of which supports several coded channels, etc., thus generating a hierarchy of channels at different levels which use different methods of obtaining isolation from other channels.

[0061] In accordance with the present invention the term demultiplexing will be used to refer to a process whereby a plurality of concurrently transmitted communications on a communication line are separated into the transmission support units of the lowest level in any hierarchy, i.e. into elemental transmission support units or elemental channels. Hence, time demultiplexing is the separation of a serial stream of time division channels into the individual channels, each separated channel or channels being associated with one time slot. Code demultiplexing is the separation of several concurrently transmitted differently coded communications into the individual channels, each separated channel or channels only having one code. Frequency demultiplexing is the separation of several concurrently transmitted communications at different frequencies or in different frequency bands into the individual channels, each separated channel or channels being at one frequency or on one frequency band. Multiplexing is the reverse of any of these demultiplexing procedures. Alternative words for switching are routing or connecting.

[0062] In accordance with the present invention "partial demultiplexing" refers to a process whereby a plurality of concurrently transmitted communications on a communication line are separated into transmission support units of which some have a higher level than the

lowest level in any hierarchy, i.e. not completely into elemental transmission support units or elemental channels. The result of partial demultiplexing is, in accordance with one apsect of the present invention, a process whereby a plurality of concurrently transmitted communications on a communication line are separated into a group or groups of elemental support units on one or more communication lines and an individual elemental support unit or support unoits on a communication line.

[0063] In an embodiment of the invention a cross-connect device with 2 input and 2 output fibres and a method of cross-connect switching based on serial space switching is described, with each fibre carrying N_l wavelength channels. In particular, the present invention includes progressive serial space switching in which a cross-connect is configured as a linear series of modules, each module performing a portion of the total space switching. The device may readily be extended to a cross-connect with more input fibres. In another embodiment of the invention a cross-connect device with, and a method for, N_f input and output fibres, with each fibre carrying N_l wavelength channels is considered. The device is not based on a decomposition into devices with two inputs and outputs but on serial space switching, in particular progressive serial space switching. In a third and fourth embodiment switching methods for respectively N_f and two wavelength channels are considered.

[0064] As indicated above, conventional cross-connects demultiplex all the channels before switching and multiplex the switched channels onto the output fibres after switching. Fig. 4A shows schematically an optical cross-connect switching device 100 in accordance with an embodiment of the present invention with 2 input (101, 102) and 2 output optical (201, 202) fibres whereby each of the fibres 101, 102, 201, 202 carries 2 wavelength channels per fibre. The device 100 does not use the conventional demultiplexing of all channels before switching. The cross-connect switching device 100 includes a space switch 18 that precedes a demultiplexing or partial demultiplexing step using filters 20 followed by a further smaller cross-connect switching device 19. The 2x2-space switch 18 is configured so that it switches the group of channels on entire fibres 101, 102 if more than half (2 in Fig. 4) of all channels have to be cross-connected from an input fibre 101; 102 to the other output fibre 202; 201, respectively (and vice-versa, i.e. when more than half of all channels have to be cross-connected from input fibre 102 to output fibre 201). This switching implies that at least half of the channels have been switched by the space switch 18 to the correct output fibre 210, 202 and a maximum of half of the wavelength channels are left to be cross-connected in the further cross-connect switching device 19. The channels which have been switched onto their correct output fibre 201, 202 by the space switch 18 are selectively transmitted past the further cross-connect switching device 19 by partial demultiplexing, i.e selecting of these channels by means of splitters 21-1, 21-2 and the filters 20-1, 20-4 along fibres 113, 114 and directly feeding these partially demultiplexed or selected channels to combiners or multiplexers 22-1 and 22-2 and so to the respective output fibres 201, 202. A splitter 21-1, 21-2 duplicates all the channels from one output fibre 101, 102 of space switch 18 onto its output fibre 111: 112. A splitter 21 and a filter 20 together select one channel, e.g. partially demultiplex the group of channels to obtain one channel thereof. The output fibres 111, 112 of space switch 18 are also connected to the further cross-connect switching device 19. The relevant filter 20-1 ... 20-4 is set to select the communication channel with the wavelength which may be transmitted along fibre 113, 114 directly to the output fibre 201, 202, respectively. Preferably, filters 20-1....20-4 are tuneable so that the cross-connect switching device 100 may be adaptively configured to changing traffic. Hence, the combined use of tuneable filters 20 and splitters 21 results in seletive partial demultiplexing in which individual channels may be selectively demultiplexed from a group of channels.

[0065] As shown, this cross-connect switching device 100 does not include wavelength conversion. The smaller further cross-connect switching device 19 only switches half the number of channels (2) per fibre which are input to the space switch 18 and can therefore be of half the size of a conventional cross-connect switch which follows a demultiplexer. In the cross-connect 100 of the embodiment of Fig. 4A, only 2 channels have to be cross-connected by the further cross-connect switching device 19. However, it is not known which 2 of the 4 channels have to be cross-connected. Hence, it is preferable if tuneable filters 20-2 and 20-3 are provided on fibres 111 and 112, respectively after splitters 21-1, 21-2 to select the channels which will be switched in a further space switch 13. The output from the further cross-connect switching device 19 and the filters 20-1 and 20-4 are fed to multiplexers 22-1 and 22-2, respectively for multiplexing of the channels onto the relevant output fibres 201, 202.

[0066] In the embodiment shown in Fig. 4A, tuneable filters 20-2 and 20-3 are preferably used on each of the fibres 111; 112 leading from the splitters 21-1, 21-2 to the further cross-connect switching device 19. In accordance with a modification of this embodiment shown in Fig. 4B, the filters 20-2, 20-3 on fibres 111, 112 may be placed after the space switch 13 and before the multiplexers 21-1, 21-2 while still providing the same functionality due to the linear nature of the filtering and switching processes. From the embodiments in Figs. 4A and B it can be seen that the further space switch 13 and the filters 20-2 and 20-3 form a select and cross-connect switching unit 19 in accordance with the present invention. In the special case of this embodiment, select and cross-connect unit 19 is a 2x2 optical cross-connect 2,1 (OXC (2,1)) which is the final switching operation before multiplexing onto the output fibres 201, 202. In a more general case with more than two input fibres 101,

102 and more than 2 wavelength channels per fibre. the select and cross-connect switch unit 19 switches more channels and may itself be built up of further space switching and select and cross-connect units.

[0067] From the above description certain aspects of the present invention may be understood. The communication channels on input lines 101, 102 are grouped together and are switched en bloc in space switch 18 in these groups. Additionally, individual channels are partially demultiplexed out of the group using a selector formed by a filter 20 and splitter 21. The seleted channel or channels is (are) directed to the relevant output fibre 210, 202. A first aspect of the present invention is to group a plurality of communication channels into one or more groups and to switch these groups in their entirety and a second aspect is to partially demultiplex (select) individual channels from at least one group of channels and the first and second aspects are combined in such a way that any communication channel on an input fibre of a cross-connect switching device in accordance with the present invention may be switched to any one output fibre thereof.

[0068] The cross-connect switching device 100 of Fig. 4 can be extended to a cross-connect switching device for a larger number of wavelength channels per fibre. Figs. 5A and B illustrate this and show the extension to a cross-connect switching device 200, 300 having 4 and 8 wavelength channels per fibre, respectively. In general. for a two input-fibre system with any number of wavelength channels per fibre, a first 2x2 space switch 18 can be used to switch the groups of channels associated with entire fibres if more than half of all wavelength channels of these fibres have to be cross-connected to another fibre. The space switch 18 is followed by a further and smaller cross-connect switching device 19 having 2 input and 2 output fibres but with only half of the number of channels per fibre to be switched compared with the cross-connect switching device 100, 200, 300. The cross-connect switching device 19 is of smaller dimension than cross-connect switching device 100, 200, 300 and can be either made from a conventional 2x2 cross-connect switch or may itself be made of a cross-connect switching device similar in structure to device 100 but smaller in dimension, i.e. it may include a further 2x2 space switch 18 connected via splitters to an even smaller cross-connect switching device and so on. In these embodiments, the filters preferably have the necessary tuneability to be able to select any one of the channels on the input fibres 101, 102.

[0069] For example, a further embodiment of the present invention is shown schematically in Fig. 5A and includes a cross-connect switching device 200 having two input fibres 101, 102 feeding four wavelength channels per fibre to a 2x2 space switch 18. The 2x2 space switch 18 is used to switch the groups of channels of entire fibres (en bloc) if more than half of all wavelength channels on these fibres have to be cross-connected to another output fibre 202, 201. Partial demultiplexing to extract individual channels is performed by a combination of splitters and filters. Splitters 21-1 and 21-2 are provided respectively on the output fibres 111, 112 of the space switch 18. The splitters 21-1 and 21-2 duplicate the four channels on each fibre 111, 112 onto two fibres 113, 115; 114, 116 respectively with the channels on fibres 111 and 112 also being fed directly to a 2x2 cross-connect cross-connect switching device 19 (OXC 2,2). The wavelength channels destined for an output fibre 201, 202 without switching in the device 19 are selected out by filters 20-1, 20-2, 20-3, 20-4 on fibres 113. 115 and 114, 116 respectively. The remaining half of the channels (two per fibre) on fibres 111, 112 respectively are switched by the 2x2 cross-connect switching device 19 which can switch any one of the two channels per input fibre onto any one of its output fibres. The outputs from switch 19 and filters 20-1....20-4 are multiplexed or combined in combiners or multiplexers 22-1 and 22-2 onto output fibres 201, 202.

[0070] The extension of this embodiment to 8 channels per input fibre 101, 102 is shown in Fig. 5B. In the cross-connect switching device 300 in accordance with this embodiment a first 2x2 space switch 18 can be used to switch the groups of wavelength channels of entire fibres if more than half of all wavelength channels of these fibres have to be cross-connected to another fibre. Splitters 21-1 and 21-2 duplicate the channels on the output fibres 111, 112 from space switch 18 onto four additional fibres 113, 115, 117, 119 and 114, 116, 118, 120 respectively. Tuneable filters 20-1, 20-2, 20-3, 20-4 select the wavelength channels which should be transmitted directly to output fibre 201, whereas tuneable filters 20-5, 20-6, 20-7, 20-8 select the wavelength channels which should be transmitted directly to output channel 202. Tuneable filters 20 and splitters 21 form a partial demultiplexer for selective extraction of individual channels from groups of channels on the input fibres. The remaining channels (i.e. those not selected in the partial demultiplexing step and which make up half of the total channels per fibre, which equals 4) are switched by the optical cross-connect switching device 19 which in this case is a two fibre input, four channels per fibre switch (OXC 2, 4). The outputs from the filters 20-1....20-8 and the cross-connect switching device 19 are combined or multiplexed in multiplexers or combiners 22-1 and 22-2 onto the respective output fibre 201, 202.

[0071] The advantages of the cross-connect switching devices 100, 200, 300 described above are that any cross-connect 100, 200, 300 can easily be upgraded to a higher number of wavelength channels per fibre by using progressive serial space switching which will be described in more detail below. Further, there is a significant reduction in the number of space switches required. For a cross-connect using a modular build-up and progressive serial space switching in accordance with the present invention no limit is foreseen as to the type of space switch and/or tuneable filter used. Cross-connect switching devices 100, 200, 300 can also be

used in accordance with the present invention as at least one of the 2,2^M optical cross-connects (OXC 2, 2^M) of the structure as shown in Fig. 3 for more than 2 input and output fibres. The reduced number of elementary 2x2 space switches can be illustrated for the case of high density WDM with 64 wavelength channels per fibre and for a cross-connect of 4 input and output fibres. The normal architecture (Fig. 3) requires 384 switches and the present invention only requires 42 space switches to achieve the same results. A further advantage is that the cross-connect 100, 200, 300 can have a very simple structure if its dimension is fixed.

[0072] A cross-connect 400 in accordance with an embodiment of the present invention using progressive serial space switching for the case of 2 fibres and 8 channels per fibre is shown schematically in Fig. 6. This cross-connect 400 consists of 3 stages 410, 420, 430. The first stage 410 consists of a series of nested 2x2 space switches 18-1, 18-2, 18-3, 18-4, each combined with its own splitters 21-1-1, 21-2-1....21-2-3 and this stage can be fabricated as a photonic integrated circuit (PIC). The second stage 420 includes a plurality of filters 20-1.... 20-16. Preferably these filters are tuneable filters. The filters 20-1.....20-16 select out those wavelength channels which are to be passed to the respective output fibre 201, 202 without going through the next space filter 18 in the cascade thus forming with a splitters a distributed partial demultiplexer. Note that the filters 20 directly connected to the last switch 18-4 of the cascade of switches 18-1....18-4 are placed after the space switch 18-4. This does not change the functionality of the device due to the linearity of the operations switching and filtering. Each space switch 18-1....18-4 is used to switch all the wavelength channels of entire input fibres if more than half of all wavelength channels of these fibres have to be cross-connected to another fibre. Each 2x2 space switch 18-1...18-4 has two input fibres but the number of channels per fibre which are to be actively selected decreases by a factor of two at each stage of the serial cascade of space switches 18-1... 18-4. Hence, this type of switching is described in accordance with the present invention as progressive serial space switching.

[0073] In the above embodiments of the present invention wavelength conversion has not been included in order to simplify the explanation. The principle of switching groups of channels first in the space domain can also be applied when full connectivity and wavelength conversion is required. Cross-connect switching devices 100 which are further embodiments in accordance with the present invention are shown schematically in Figs. 7A and B. Reference should be made to Fig. 4A for a general description of the cross-connects 100 of Fig. 7A and B. Here, only the differences will be discussed. As shown schematically in Fig. 7A a wavelength converter 23-1, 23-2, 23-2, 23-4 is added into each fibre having a tuneable filter 20 before the channels on these fibres are combined or multiplexed in multiplexers 22-1 and 22-2. The embodiment of Fig. 7A maintains full modularity, i.e. the sub cross-connect unit 13 can in general be formed from further cross-connect switching devices 100 but with a smaller number of channels per fibre by progressive serial space switching in accordance with the present invention. Cross-connect switching devices 100 in accordance with this embodiment can be build in a similar modular fashion as the ones without wavelength conversion described with reference to Fig. 6 above.

[0074] Placing a wavelength converter 23 in each fibre as shown in Fig. 7A makes use of more converters 23 than are required as a minimum. A further reduction in number of components is possible by noticing that at most half of the channels have to be converted in wavelength. This follows from the fact that the number of channels is identical for all output fibres. A cross-connect 100 shown schematically in Fig. 7B is also an embodiment of the present invention and provides a reduction in the number of required wavelength converters by a factor 2. Only two wavelength converters 23-2 and 23-3 are used in the output fibres of the switch 13. One disadvantage of such a cross-connect 100 as shown in Fig. 7B is that it is not as modular as the one of Fig. 7A, e.g. when upgrading the cross-connect 100 of Figure 7B to a higher number of channels per fibre (e.g. to the case of 4 wavelength channels per fibre using progressive serial space switching as explained with reference to the embodiment of Fig. 6), the cross-connect 100 of Fig. 7B for 2 wavelength channels per fibre must be adapted before further extending this cross-connect 100 to a cross-connect for 4 channels per fibre.

[0075] In accordance with the present invention it is particularly preferred if the progressive serial space switching concept illustrated by the embodiment of Fig. 6 is used but the present invention is not limited thereto. A cross-connect 100 for 2 fibres and 2^M channels can also be build from a 2x2 space switch 18 and a conventional cross-connect 19 for 2 fibres and $2^{(M-1)}$ channels, as shown schematically in Fig. 5B for M=3. The reduction in components will be less but still noticeable. In such a cross-connect switching device at least switching of entire groups is carried out (space switch 18) as well as at least one step of selection of individual wavelength channels (tuneable filters 20).

[0076] The splitters 21, combiners or multiplexers 23 and the tuneable filters 20 in accordance with the present invention may be replaced by equivalently functioning devices such as tuneable demultiplexers and multiplexers, e.g. add-drop multiplexers (OADM's). If a cross-connect switching device for 2 fibres and $2^{(M-1)}$ channels in accordance with the present invention makes use of tuneable add-drop multiplexers, only half the number of OADMs are required than would be necessary in a conventional switch. A further embodiment of a cross-connect switching device 500 in accordance with the present invention is shown schematically in Fig. 8. A 2x2 space switch 18 has two input fibres 101, 102

and can be used to switch the group of communication channels on entire fibres if more than half of all wavelength channels of these fibres have to be cross-connected to another fibre. Output fibres 111, 112 of space switch 18 carry all the wavelength channels on each of these fibres towards the respective output fibres 201, 202. An OADM 24-1, 24-2, 24-3, 24-4 is used to extract (drop) one of the channels from the respective fibre 111, 112 to a 4x4 switch 25. All the channels that, after the first space switch 18, are not dropped by the OADM's 24 (these are at least 50% of the channels) are routed outside the smaller cross-connect 25 and can be kept together in a wavelength channel group which is smaller than the group switched in space switch 18. This reduction in tuneable OADM's 24 applies however only if a cross-connect of 2^M fibres and 2^M channels is build from a 2x2 space switch and a cross-connect for 2^M fibres and $2^{(M-1)}$ channels.

[0077] Cross-connect switching devices in accordance with the present invention are not restricted to systems with a power of 2 as the number of channels per fibre. In fact, cross-connects in accordance with the present invention for 2^M+1, 2^M+2, ..., $2^{M+1}-1$ channels per fibre require the same number of space switches 18 as a cross-connect for 2^M channels per fibre and just require more filters 20 and different splitters 21 and combiners 22. This is illustrated by comparing a cross-connect switching device 400 for 4 channels per fibre in Fig. 9A with a cross-connect switching device 400 for 7 channels per fibre in Fig. 9B, both of which are embodiments of the present invention. Figs. 9A and B have three stages 410, 420, 430 as already described for the embodiment of Fig. 6. The second stage 420 includes a plurality of tuneable filters 20 and the third stage 430 includes the combiners or multiplexers 22. The main differences lie in the first stage 410. In Fig. 9A the splitters 21 of the first stage of the cascade 18-1 to 18-3 of serially arranged 2x2 space switches 18 duplicate the 4 channels per fibre on the output fibres 111, 112 of the first space switch 18-1 onto fibres 113, 115; 114, 116. The duplicate of the channels per fibre, i.e. 4, are fed directly towards the output fibres 201, 202 and two of the channels are selected therefrom (partially demultiplexed) by the filters 20-1, 20-2, 20-7, 20-8. The channels on fibres 111, 112 are fed to a second space switch 18-2. In the second and third stages of the cascade of space switches 18 the above process of switching groups of channels and selection of individual channels is carried out, two further channels per output fibre being selected by filters 20-3, 20-6 and 20-4 and 20-5 in the second and third stage of the cascade, respectively. In the embodiment of Fig. 9B, the splitters 21 of the first stage of the cascade duplicate the channels on the output fibres 111, 112 of the first space switch 18-1 into 4 parallel fibres while the channels on output fibres 111, 112 are fed directly to the next space switch 18-2 in the series. On the eight fibres 113, 115, 117, 119; 114, 116, 118, 120 one channel per output fibre are selected by the filters 20-1, 20-2, 20-3, 20-4 and 20-11, 20-12, 20-13, 20-14, respectively. In the second stage of the cascade after the space switch 18-2, the channels on the output fibres of switch 18-2 are duplicated into two fibres, from which two channels are selected for the relevant output fibre 201, 202 by filters 20-5, 20-6, 20-9, 20-10. The final two channels are selected in the third stage of the cascade by filters 20-7 and 20-8. If a further channel is added to the input fibres 101, 102, i.e. to make it up to 8 channels per fibre, either and additional stage must be added to the cascade of space switches 18 (see Fig. 6 as an example of this structure) or one of the space switches 18, particularly the last in the cascade 18-3 must be changed to a conventional cross-connect switch which has 2 output fibres and any of the incoming 2 channels per fibre on this last stage can be switched to one of the two output fibres. Both of these alternatives are separate embodiments of the present invention.

[0078] A cross-connect switching device in accordance with the present invention can be implemented with fixed wavelength filters 20 if all the channels can be converted in wavelength prior to entering the cross-connect device. By selecting the wavelength conversion appropriately, the required selection of wavelength channels by a cross-connect with non-tuneable filters can be made as adaptable as a cross-connect with tuneable filters. Such wavelength conversion can be added intentionally or can be present already as part of e.g. regeneration circuits. A cross-connect 600 in accordance with an embodiment of the present invention with fixed wavelength filters 20 and preceded by wavelength conversion is depicted schematically in Fig. 10. This device includes the three stages 410, 420, 430 of Figs. 6, 9A or 9B with the modification in the second stage 420 that the filters 20 are of fixed wavelength. In addition a fourth stage 440 is added in which the groups of channels on the two input fibres 101, 102 are first each demultiplexed in demultiplexers 26-1 and 26-2 and each of the plurality of outgoing wavelength channels can be wavelength converted in wavelength converters 27 and then multiplexed onto two fibres in multiplexers 28 before being fed to the space switch 18-1. It is necessary to add additional wavelength conversion possibility after or within the cross-connect 600 if the channels on the output fibres 201, 202 are required to have the same wavelength as the incoming channels on the input fibres 101, 102.

[0079] Moreover, if a reduced functionality can be tolerated, the cross-connect 600 of Fig. 10 may be used without wavelength conversion. Such a cross-connect 700 which is an embodiment of the present invention is shown schematically in Fig. 11. This cross-connect 700 has the cascade of space switches 18-1....18-3 as has been described with respect to Figs. 6 and 9, however, channels on the output fibres of the splitters 21 and the final switch 18-3 are wavelength selected and combined or multiplexed by the multiplexers 29-1, 29-2 which have an equivalent function to the fixed filters 20 and the mul-

tiplexers 23 of the cross-connect 600 of Fig. 10. The cross-connect 700 of Fig. 11 has the disadvantage that only groups of channels can be cross-connected in accordance with fixed wavelengths rather than being adaptively selected by tuneable filters, but this cross-connect 700 has the great advantage of a simple structure that is most suited for implementation as a photonic integrated circuit or PIC.

[0080] In the above description of the present invention only two input fibres 101, 102 have been considered. The present invention is not limited thereto but may include any number of input fibres. Cross-connect devices with more than two input and output fibres can be constructed, for instance, as indicated in Fig. 3 by using a plurality of 2x2 cross-connect switching devices (OXC of Fig. 3) of which at least one is a switching device in accordance with one of the embodiments of the present invention.

[0081] Alternatively, the cross-connect device and/or method consisting of alternating space switching and demultiplexing including possibly also filtering and progressive serial space switching in accordance with the present invention can also be applied directly to the case where there are more than 2 input and output fibres. Fig. 12 shows schematically a cross-connect device 800 in accordance with another embodiment of the present invention for 4 input and 4 output fibres 101, 102, 103, 104. For explanation purposes it may be assumed that each of the fibres is carrying 8 wavelength channels but the present invention is not limited thereto. The device 800 has a first 4x4 space switch 7. In the switch 7 the groups of wavelength channels of entire fibres are switched, meaning that all channels belonging to the same input fibre 101, 102, 103, 104 are switched towards the same output fibre 201, 202, 203, 204. The group of channels on each input fibre 101....104 are switched if more than a number of channels "A" have to be switched towards an output fibre, the numebr "A" being equal to or greater than the quotient of the number of channels per fibre and the number of input fibres (here this equals 25%). After the first switch 7, splitters 8-1, 8-2, 8-3 and 8-4 duplicate the channels of each of the output fibres 111, 112, 113, 114 of switch 7 onto two further fibres. On these fibres two channels per fibre (total 8) are filtered out (partially demultiplexed) by tuneable filters10-1, 10-2, 10-3, 10-4, 10-5, 10-6, 10-7, 10-8. Then a cross-connect device 9, with 4 input and 4 output fibres, the fibres carrying 6 channels per fibre, is used to switch the remaining channels. Finally, the selected channels are multiplexed or combined by multiplexers or combiners 11-1, 11-2, 11-3, 11-4. Conceptual similarity will be noticed between the cross-connect device 800 of Fig. 12 and the device 300 of Fig. 5B with the difference that there are now four input and output fibres. Just as described with reference to Fig. 6, the cross-connect device 9 can be constructed in a progressive modular manner as a smaller version but of the same type as the original cross-connect device 800 using progressive serial space switching. For instance, this cross-connect device 9 can comprise a further 4x4 space switch, means for splitting off 2 channels per output fibre of the further 4x4 space switch and a further 4x4 cross-connect device with fibres carrying 4 channels each. The principle of progressive serial space switching in accordance with the present invention may be continued by splitting off 1 channel per fibre from the outputs of the further 4x4 cross-connect switch and this procedure repeated until a final 4x4 cross-connect device with four output fibres each carrying 1 channel is obtained. Note that, as has been mentioned above, the nested construction of space switches in a serial cascade as exemplified by Fig. 6 can also be stopped at an intermediate position with a final conventional cross-connect device capable of switching any channel of a predetermined number of channels per fibre to any one of the output fibres.

[0082] In general in accordance with a generalised embodiment of the present invention, for a cross-connect with N_f input and output fibres and N_l channels per fibre, an N_f by N_f space switch is provided, after which a maximum of $[N_l/2\ (N_f -1)]$ fibres are split off or partially demultiplexed per output fibre of the N_f by N_f space switch, with $[N_l/2\ (N_f -1)]$ being the smallest integer larger than or equal to $N_l/2\ (N_f -1)$. After that stage, a cross-connect with N_f input and output fibres with a minimum N_l-$[N_l/2\ (Nf -1)]$. channels per fibre is provided, and so on.

[0083] In accordance with the present invention a combination of progressive and non-progressive serial space switching (direct and indirect serial space switching) can be applied. For instance the cross-connect device 800, with 4 input and 4 output fibres, each carrying 6 channels, shown in Fig. 12, can be constructed equivalently by using a plurality of OXC as is shown in Fig. 3 in which at least one of the OXC is a cross-connect switching device in accordance with an embodiment of the present invention. Such a cross-connect switching device 900 in accordance with a further embodiment of the present invention is shown schematically in Fig. 13. The complete device 900 has 5 input fibres 101-105 and five output fibres 201-205. Within device 900 there are provided a plurality of switching modules 1-1....1-4. At least one of these modules 1 has less number of input and output fibres than the main device 900. For instance, module 1-1 has two input (101, 102) and output fibres (301, 302). Module 1-1 is a cross-connect switching device in accordance with an embodiment of the present invention, e.g. as shown in Fig. 6. For instance, it may include three space switches 18 in a cascade with splitters 21, tuneable or non-tuneable filters 20 and combiners 22.

[0084] In the above description of embodiments of the present invention splitters 20 and multiplexers or combiners 22 are used. In the various drawings and embodiments splitters 20 and combiners 22 are represented as in Fig. 14 -left part. Note however that the structure

in Fig. 14 -right part is equivalent from a functional point of view and may be used instead. Further, the splitters mentioned with respect to any of the embodiments of the present invention may have a freely selectable splitting ratio, i.e. the ratio indicating the power distribution spread over the splitter's output fibres. In any cross-connect device in accordance with the present invention any suitable splitting ratio is acceptable.

[0085] A cross-connect switching device 50 in accordance with a further embodiment of the present invention is shown schematically in Fig. 15. Whereas several of the previous embodiments have been described with reference to serial space switching, the device 50 makes use of parallel space switching. The cross-connect device 50 may be represented as five stages 501 to 505. In the first stage 501, the channels on incoming lines or fibres 101, 102 are demultiplexed. For instance, as shown in Fig. 15 there are 8 channels per fibre 101, 102 and these are demultiplexed by means of splitters 51 and tuneable filters 52, one for each channel. In optional stage 502 the wavelength of each of the demultiplexed channels can be converted using wavelength converters 53, one per demultiplexed channel. Wavelength conversion is used to avoid conflicts when recombining those channels onto an output fibre which have the same wavelength. In stage 503 the demultiplexed channels are combined using combiners or multiplexers into groups of channels. These groups may include a single channel or a subset of the total number of channels. The effect of stages 501 to 503 is to partially demultiplex groups of channels on the input fibres 101, 102 into individual channels and new groups of channels. This is achieved by a complete deultiplexing step in stage 501 followed by a partial recombining step in stage 503. This is to be contrasted with the previous embodients in which the partial demultiplexing step to select individual channels was done by splitting and filtering. In stage 504 the grouped channels are fed to parallely arranged 2x2 space switches 55 which switch all the wavelengths of one group on one input fibre 101, 102 towards output fibres 201, 202 if more than half of the channels of an input fibre 101, 102 must be switched towards a particular output fibre 202, 201. Finally, in step 505, the switched groups are combined in combiners or multiplexers 56 onto the output fibres 201, 202.

[0086] This embodiment makes use of the steps of demultiplexing, grouping, group switching and recombining in order to be able to switch any channel from an input fibre 101, 102 to any output fibre 201, 202. The group switching is done in parallel space switches 55. If there are more than two input fibres then for Ni input fibres and Nc channels per fibre group switching is carried out if more than Ni/Nc channels are to be switched to another ouptut fibre.

[0087] Additional aspects of the present invention are:

Aspect 1. A cross-connect device with N_f first input fibres and N_f first output fibres, being able to switch N_f * N_l channels, N_f * N_l being equal or greater than four, the channels being equally distributed over the first input fibres comprising:

> a switch, having as input fibres the N_f first input fibres, and N_f second output fibres, the switch switching for each of the first input fibres all channels to one of the second output fibres;
> N_f splitters, each having as second input fibre one of the second output fibres and a plurality of third output fibres;
> a selecting and switching device with N_f third input fibres and N_f fourth output fibres, being able to switch a first number of channels, the first number being strictly smaller than N_f * N_l, the selecting and switching device switching a subset of the channels of the second output fibres;
> a plurality of filters, part of the filters having as fourth input fibre one of the third output fibres, and one fifth output fibre; and
> a plurality of combiners, each having a plurality of fifth input fibres and having as output fibre one of the first output fibres, each of thecombiners combines a subset of the third output fibres with one of the fourth output fibres.

Aspect 2. The cross-connect device according to aspect 1, wherein a number D is the smallest integer larger than or equal to N_l /2 (N_f -1), a number E is a non-zero integer smaller or equal to D, and the first number is equal or larger than N_f *(N_l-E).

Aspect 3. The cross-connect device according to aspect 2, wherein the splitters have E+1 output fibres, the combiners have E+1 input fibres and the number of filters in the plurality of filters equals N_f*E.

Aspect 4. The cross-connect device according to aspect 3, wherein

> each of the second output fibres is connected to one of the second input fibres;
> each of the third input fibres is connected to one of the third output fibres, the third input fibres not being connected to the same splitter; and
> each of the fourth input fibres is connected to one of the third output fibres.

Aspect 5. The cross-connect device according to aspect 4, wherein

> each of the fourth output fibres is connected to one of the fifth input fibres, the fourth output fibres not being connected to the same combiner; and
> each of the fifth output fibres is connected to one of the fifth input fibres.

Aspect 6. The cross-connect device according to aspect 5, wherein the selecting and switching device is configured in such a way that it has essentially the same functionality and structure as the cross-connect device.

Aspect 7. A cross-connect device with two first input fibres and two first output fibres, being able to switch a first even amount of channels, the first amount being equal or greater than four, the channels being equally distributed over the two input fibres comprising of:

a switch, having as input fibres the first input fibres, and two second output fibres, the switch switching for each of the first input fibres all channels to one of the second output fibres;
two splitters, each having as second input one of the second output fibres, and a plurality of third output fibres;
a selecting and switching device with two third input fibres and two fourth output fibres, and being able to switch a second even amount of channels, the second even amount of channels being equal or larger than half of the first even amount of channels, the switching and selecting device switching a subset of the channels of the second output fibres;
a plurality of filters, part of the filters having as fourth input fibre one of the third output fibres, and one fifth output fibre; and
two combiners, each having a plurality of fifth input fibres and having as output fibre one of the first output fibres, each of the combiners combines a subset of the third output fibres with one of the fourth output fibres.

Aspect 8. The cross-connect device according to aspect 7, wherein the first even amount of channels equals 2^N+2*M where N is an integer strictly greater than 1, 2*M is an integer larger or equal to zero and strictly smaller than 2^N, with M an integer, a first number A being the largest integer smaller than 2^(N-2)+M/2, a second number B being an integer larger or equal to the first number A and strictly smaller than 2^(N-1)+M and the second even amount of channels being 2*B.

Aspect 9. The cross-connect device according to aspect 8, wherein a third number C is the difference between 2^(N-1)+M and the second number B, the splitters have C+1 output fibres, the combiners have C+1 input fibres and the number of filters in the plurality of filters is 2*C.

Aspect 10. The cross-connect device according to aspect 9, wherein

each of the second output fibres is connected to one of the second input fibres:
each of the third input fibres is connected to one of the fifth output fibres. the third input fibres not being connected to the same splitter: and
each of the fourth input fibres is connected to one of the third output fibres.

Aspect 11. The cross-connect device according to aspect 10, wherein

each of the fourth output fibres os connected to one of the fifth input fibres, the fifth output fibres never being connected to the same combiner: and each of the fifth output fibres is connected to one of the fifth input fibres.

Aspect 12. The cross-connect device according to aspect 11, wherein the selecting and switching device are configured such that they have essentially the same functionality and structure as the cross-connect device, except for final switching and selecting device which is able to switch a predetermined amount of channels, the amount being an even integer strictly greater than one.

Aspect 13. The cross-connect device according to aspect 12, wherein the predetermined amount of channels is equal to two;
the second selecting and switching device with two first input fibres and two first output fibres comprises:

a switch having as outputs the first output fibres and two second input fibres;
two filters, each having as input fibre one of the first input fibres and one second output fibre; and
each of the second input fibres being connected to one of the second output fibres.

Aspect 14. The cross-connect device according to aspect 12, wherein the predetermined amount of channels is equal to two;
the second selecting and switching device with two first input fibres and two first output fibres comprises:

a switch having as inputs the first input fibres and two second output fibres;
two filters, each having as output fibres one of the first output fibres and one second input fibre; and
each of the second input fibres being connected to one of the second output fibres.

Aspect 15. The cross-connect device according to aspect 14, where the cross-connect device is indicated in a photonic integrated circuit.

Aspect 16. The cross-connect device according to aspect 12, wherein the filters are tuneable.

Aspect 17. The cross-connect device according to aspect 12, wherein the filters are non-tuneable.

Aspect 18. The cross-connect device according to aspect 12, wherein each of the filters comprises a cascade of a tunable filter and a wavelength convertor.

Aspect 19. The cross-connect device according to aspect 12, where one half of the filters comprise cascades of a tunable filter and a wavelength convertor and the other half of the filters are tunable.

Aspect 20. A method for switching N_f * N_l channels being equally distributed over N_f input fibres to N_f * N_l channels being equally distributed over N_f output fibres, comprising the steps of:

defining a set of N_f intermediate fibres of a first kind;
defining a set of N_f intermediate fibres of a second kind;
switching for each of the input fibres the channels to one of the first intermediate fibres of a first kind, thereby not switching channels of different input fibres to the same intermediate fibre of a first kind; and thereafter
applying a method for switching an amount of channels being equally distributed over the intermediate fibres of a first kind to the intermediate fibres of a second kind.

Aspect 21. The method according to aspect 20, wherein the number of channels of the intermediate fibres of a first kind is determined by splitting the intermediate fibres of a first kind into a plurality of intermediate fibres of a third kind.

Aspect 22. The method according to aspect 21, where each of the output fibres at least comprises the channels of one of the intermediate fibres of a second kind.

Aspect 23. The method according to aspect 22, wherein the method for switching an amount of channels is applied to the channels of N_f intermediate fibres of a third kind.

Aspect 24. A method for switching a first even amount of channels being equally distributed over a first and a second input fibre to a first even amount of channels being equally distributed over a first and second output fibre, comprising the steps of:

defining a first and a second intermediate fibre of a first kind;
defining a first and a second intermediate fibre of a second kind;
switching all the channels of the first input fibre to the first intermediate fibre of a first kind and all the channels of the second input fibre to the second intermediate fibre of a first kind when less or equal than half of the channels of the first input fibre must be switched to the first output fibre;
switching all the channels of the first input fibre to the second intermediate fibre of a first kind and all the channels of the second input fibre to the second intermediate fibre of a second kind when more than half of the channels of the first input fibre must be switched to the second output fibre; thereafter
applying a method for switching a second amount of channels being equally distributed over the first and the second intermediate fibres of a first kind to the first and the second intermediate fibres of a second kind, the second amount being at least half of the first amount.

Aspect 25. The method according to aspect 24, wherein the second amount of channels of the first and the second intermediate fibres of a first kind are determined by splitting the first intermediate fibre of a first kind in a plurality of intermediate fibres of a third kind and the second intermediate fibre of a first kind in a plurality of intermediate fibres of a fourth kind.

Aspect 26. The method according to aspect 25, wherein the amount of channels of
the first output fibre at least comprises all channels on the first intermediate fibre of a second kind and the amount of channels on the second output fibre at least comprises of all channels on the second intermediate fibre of a second kind.

Aspect 27. The method according to aspect 26, wherein the method for switching a second amount of channels is applied to the channels of one of the intermediate fibres of a third kind and to the channels of one of the intermediate fibres of a fourth kind.

Aspect 28. The method according to aspect 27, wherein the amount of channels on the first output fibre further comprises the channels on the intermediate fibres of a third kind, except that fibre of a third kind which channels being switched by the method for switching a second amount of channels and the amount of channels on the second output fibre further comprises the channels on the intermediate fibres of a fourth kind, except that fibre of a fourth kind which channels being switched by the method for switching a second amount of channels.

Aspect 29. The method according to aspect 28, wherein at least one of the intermediate fibres of a third kind is filtered and at least one of the intermediate fibres of a fourth kind in filtered.

Aspect 30. The method according to aspect 29, wherein the first and the second intermediate output fibres of a second kind are filtered.

Aspect 31. A cross-connect device of a first kind with N_f input fibres and N_f output fibres, each input fibre carrying N_l channels comprising:

a plurality of cross-connect devices of a second kind, each of the cross-connect devices of a second kind having an amount of input fibres and output fibres strictly less than the cross-connect device of a first kind; and
at least one of the cross-connect devices of a second kind at least comprising:
a plurality of switches; and
a selecting and switching component, with an amount of input fibres and output fibres equal to the amount of input fibres and output fibres of the cross-connect device of a second kind to which the selecting andswitching component belongs and the selecting and switching component, being able to switch an amount of channels equal to the aount of input fibres of the selecting and switching component multiplied with a number strictly less than N_l.

Aspect 32. The device according to aspect 31, wherein each of the input fibres of the cross-connect device of a first kind is combined at least once by using the cross-connect devices of a second kind.

Aspect 33. A method for switching $N_f * N_l$ channels being equally distributed over N_f input fibres to $N_f * N_l$ channels being equally distributed over N_f output fibres, comprising the steps of:

a finite sequence of space switching steps; and thereafter
a switching and selecting step, for switching an amount of channels equal to N_f multiplied with a number strictly less than N_l.

Claims

1. A cross-connect switching device with N_f input lines and N_f output lines and Ni channels per line and being able to switch any of the $N_f * N_l$ input channels to one of the output lines, $N_f * N_l$ being equal or greater than four, the channels being equally distributed over the input lines, comprising:

   a switch being operatively connected to at least some of the input lines of the cross-connect switching device and being adapted to switch at least one channel group on one input line of the switch en bloc to an output line of the switch, a channel group including a plurality of channels up to a maximum of N_l channels;
   a partial demultiplexer operatively connected to the switch for selecting at least one individual channel from at least one channel group; and
   a combiner unit for combining the selected individual channel onto an output line of the cross-connect switching device.

2. The cross-connect switching device according to claim 1, wherein the partial demultiplexer is adapted to generate a further channel group as well as the one selected channel, further comprising a further switch located between the partial demultiplexer and the combiner unit and receiving the output of the partial demultiplexer and being adapted to switch the further channel group en bloc towards one of the output lines of the cross-connect switching device.

3. A cross-connect switching device with N_f input lines and N_f output lines and N_l channels per line, and being able to switch any of the $N_f * N_l$ input channels to one of the output lines, $N_f * N_l$ being equal or greater than four, the channels being equally distributed over the input lines, comprising:

   a partial demultiplexer operatively connected to at least some of the input lines of the cross-connect switching device for partial demultiplexing the channels on an input line of the partial demultiplexer into at least a group of channels and an individual channel, a channel group including a plurality of channels up to a maximum of N_l channels;
   a switch operatively connected to the output side of the partial demultiplexer, the switch being adapted to switch the at least one channel group en bloc to an output line of the switch; and
   a combiner unit for combining the individual channel onto an output line of the cross-connect switching device.

4. The cross-connect switching device according to any of claims 1 to 3, wherein the switch has N_f input lines with Nc channels per line and the switch is adapted to switch the group of Nc channels per input line to an output line of the switch if more than Nc/N_f channels of the input channels per line are to be switched to the particular switch output line.

5. The cross-connect switching device according to

any of claims 1 to 4 wherein the partial demultiplexer includes a splitting device having one input line and adapted for duplicating the channels on its input line onto a plurality of its output lines. and a selecting device for selecting the individual channel.

6. The cross-connect switching device according to any previous claims, wherein the cross-connect device is an optical cross-connect switching device.

7. The cross-connect switching device according to claim 5 or 6, wherein the selecting device comprises a filter.

8. The cross-connect switching device according to claim 7, wherein the filter is a tuneable filter

9. The cross-connect switching device according to any previous claim, wherein the switch, has N_f second output lines and the N_f first input lines as input lines, and the switch switches for each of the first input lines all channels to one of the second output lines;
the partial demultiplexer comprises:

N_f splitters, each having as second input line one of the second output lines and a plurality of third output lines, and
a plurality of filters, part of the filters having as fourth input line one of the third output lines, and one fifth output line;
a selecting and switching unit with N_f third input lines and N_f fourth output line which is able to switch a first number of channels, the first number being strictly smaller than $N_f * N_l$, the selecting and switching unit switching a subset of the channels of the second output lines; and
the combiner unit comprises:
a plurality of combiners, each having a plurality of fifth input lines and having as output line one of the first output lines, each of the combiners combining channels on a subset of the third output lines onto one of the fourth output lines.

10. A first cross-connect switching device with N_f input lines and N_f output lines, each input line carrying N_l channels, comprising:

a plurality of second cross-connect switching devices, each of the second cross-connect devices having an number of input lines and output lines strictly less than the first cross-connect switching device; and
at least one of the second cross-connect switching devices at least comprising:
a plurality of switches; and
a selecting and switching unit having an number of input lines and output lines equal to the number of input lines and output lines of the second cross-connect switching device to which the selecting and switching unit belongs and the selecting and switching unit being able to switch a number of channels equal to the number of input lines of the selecting and switching unit multiplied by a number strictly less than N_l.

11. The cross-connect switching device according to claim 10, wherein the second cross-connect switching device is a cross-connect switching device in accordance with any of the claims 1 to 9.

12. A method for switching $N_f * N_l$ channels, being equally distributed over N_f input lines, to $N_f * N_l$ channels, equally distributed over N_f output lines, there being N_l channels per line, the method comprising the step of using a combination of the following steps:

a) performing at least one switching operation in which at least one channel group is switched en bloc towards one of the output lines, a channel group including a plurality of channels up to a maximum of Ni channels;
b) partially demultiplexing to select at least one individual channel from at least one group, and
c) combining the selected individual channel onto an output line.

13. A method for switching $N_f * N_l$ channels, being equally distributed over N_f input lines, there being $N_f * N_l$ channels equally distributed over N_f output lines, the method comprising the step of using a combination of the following steps:

a) partially demultiplexing the channels on an input line into at least one individual channel and at least one group of channels, a channel group including a plurality of channels up to a maximum of N_l channels;
b) performing at least one switching operation in which the at least one channel group is switched en bloc towards one of the output lines: and
c) combining the at least one individual channel onto an output line.

14. The method according to claim 12 or 13, wherein there are N_f channel groups on N_f input lines each having Nc channels per group and a group is switched to an output line in the switching operation if more than Nc/N_f channels of the input channels per line are to be switched to the particular output line.

15. The method according to any of claims 12 to 14,

wherein the lines are optical fibres.

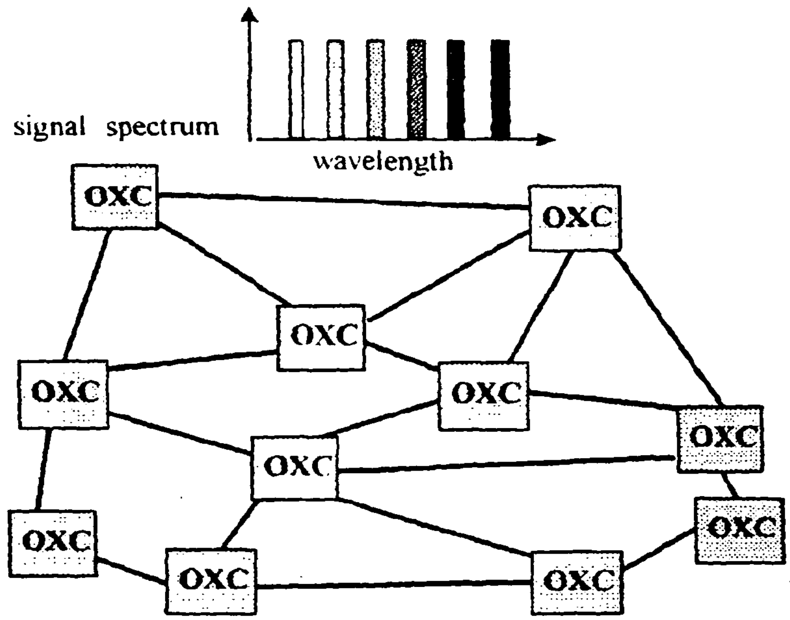

signal spectrum
wavelength
OXC
OXC
OXC
OXC
OXC
OXC
OXC
OXC
OXC
OXC
OXC
OXC

Fig. 1

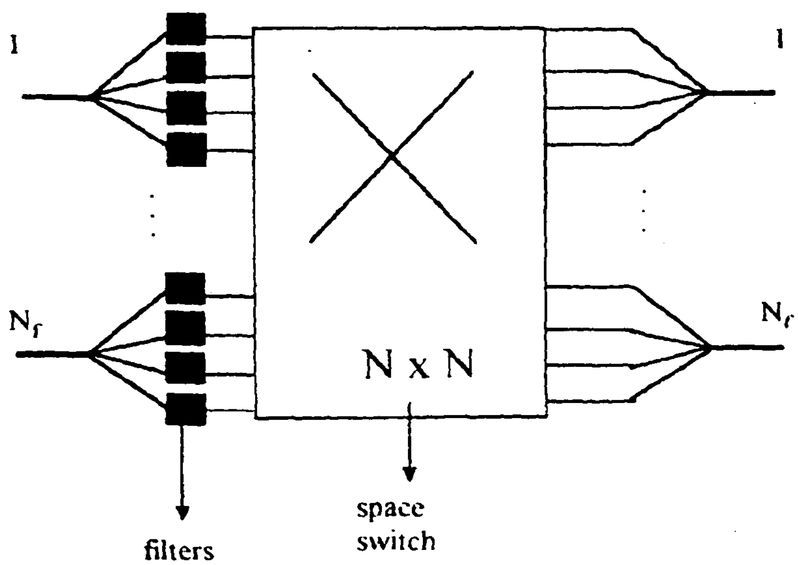

1
1
N_f
N_f
N x N
filters
space
switch

Fig. 2A

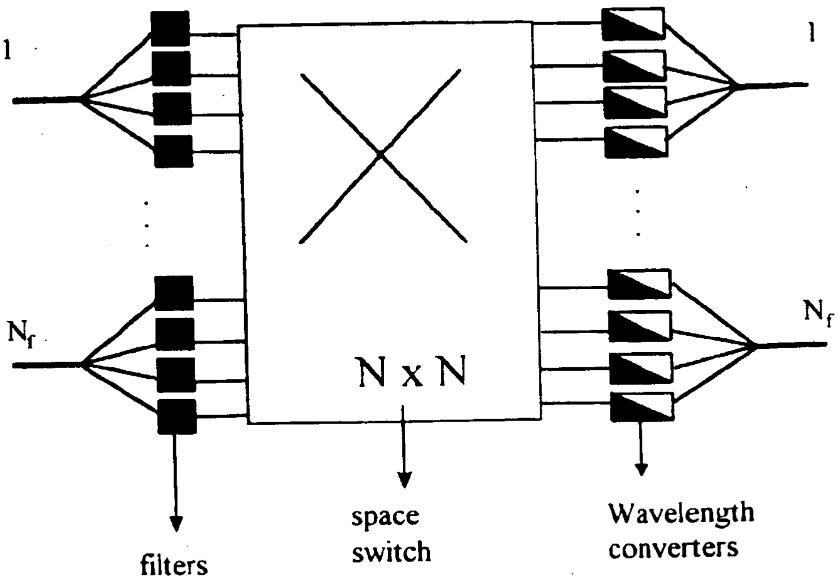

1
1
N x N
N_f
N_f
filters
space
switch
Wavelength
converters

Fig. 2B

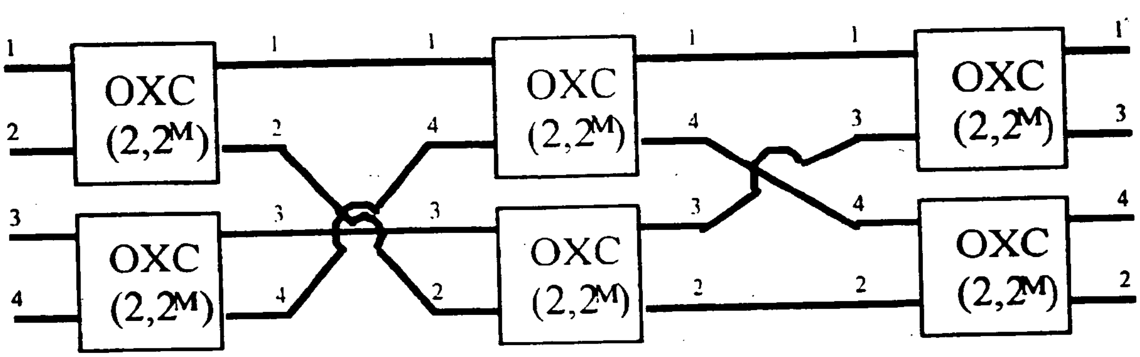

OXC
(2,2M)
OXC
(2,2M)
OXC
(2,2M)
OXC
(2,2M)
OXC
(2,2M)
OXC
(2,2M)

Fig. 3

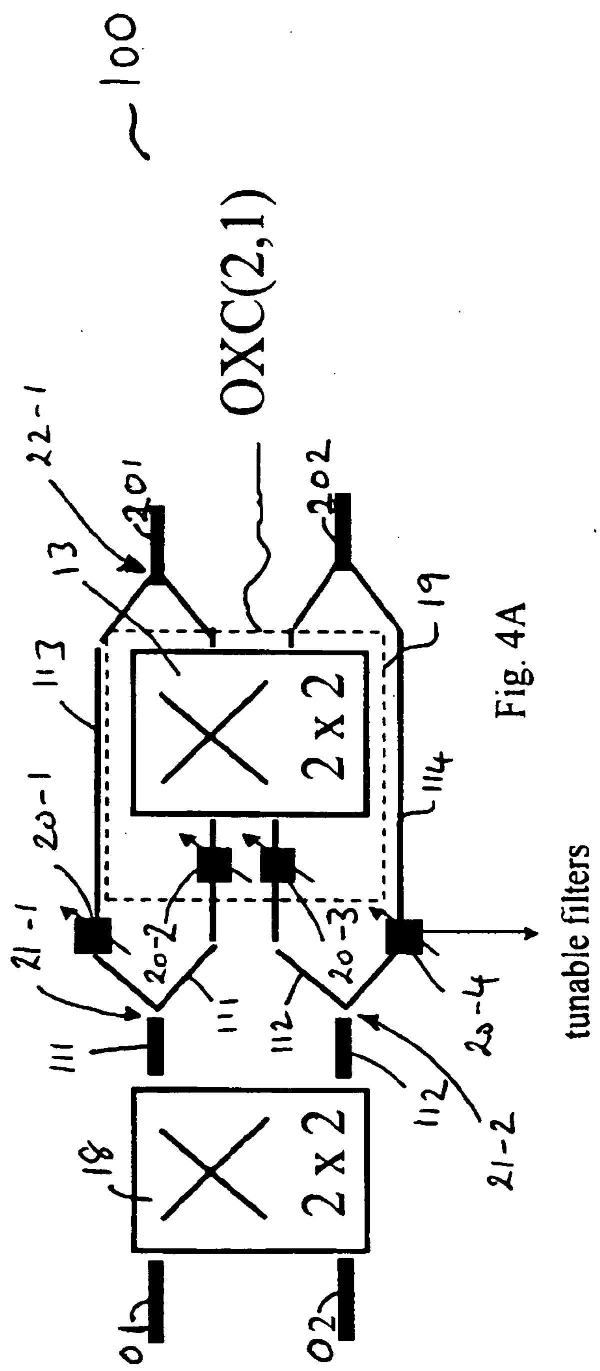

OXC(2,1)
2 x 2
2 x 2
tunable filters

Fig. 4A

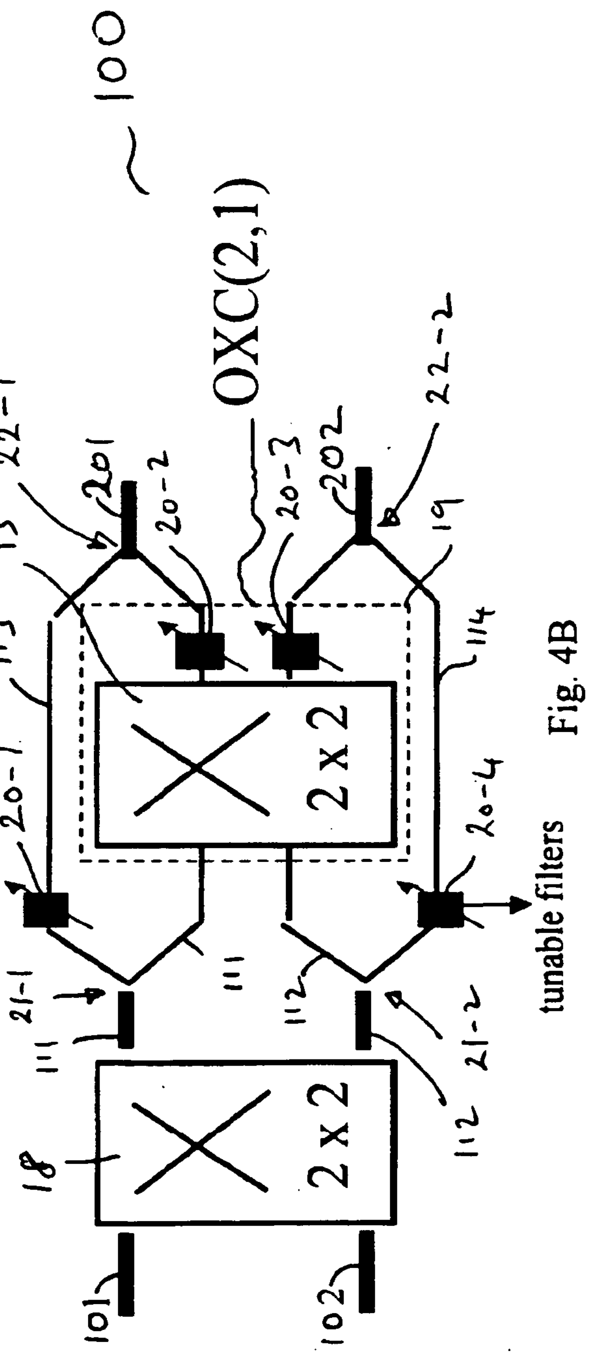

OXC(2,1)
2 x 2
2 x 2
tunable filters

Fig. 4B

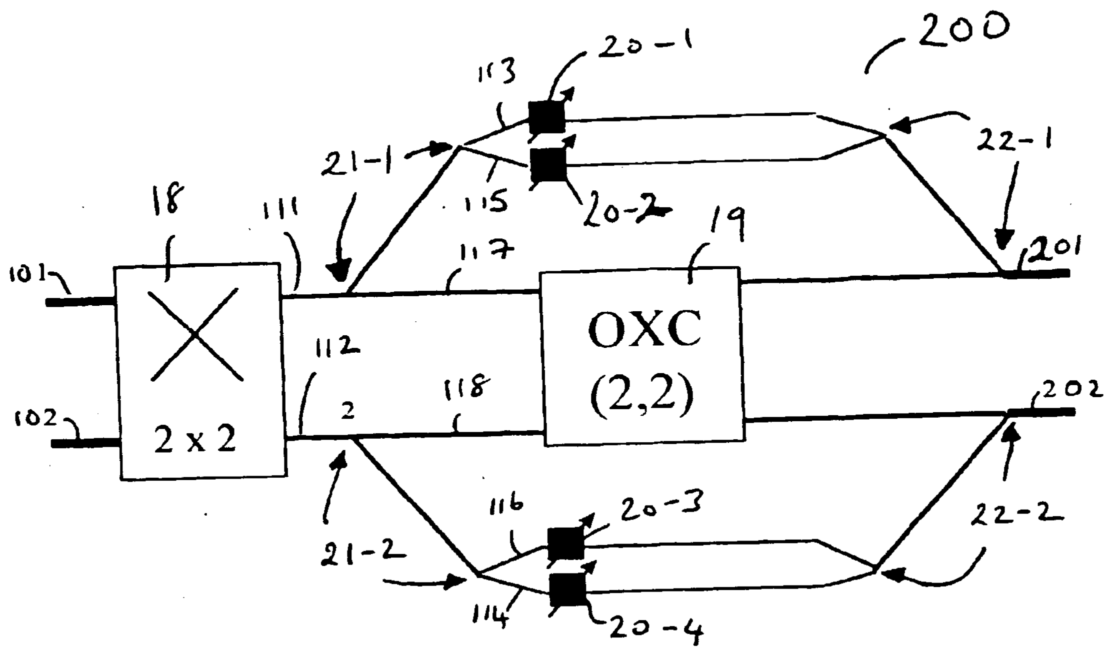

200
20-1
113
21-1
22-1
115
20-2
18
111
19
117
201
101
OXC
(2,2)
112
118
2
202
102
2 x 2
116
20-3
22-2
21-2
114
20-4

Fig. 5A

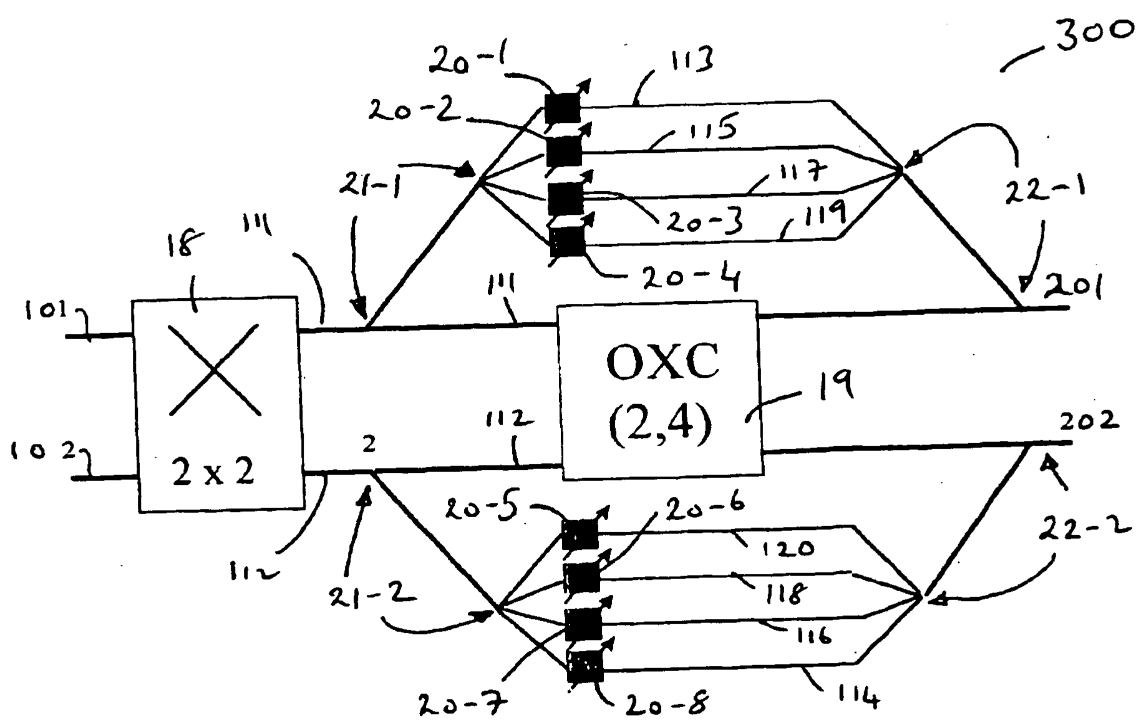

300
20-1
113
20-2
115
21-1
117
22-1
20-3
119
18
111
20-4
111
201
101
OXC
(2,4)
19
112
202
102
2 x 2
2
20-5
20-6
120
22-2
112
21-2
118
116
20-7
20-8
114

Fig. 5B

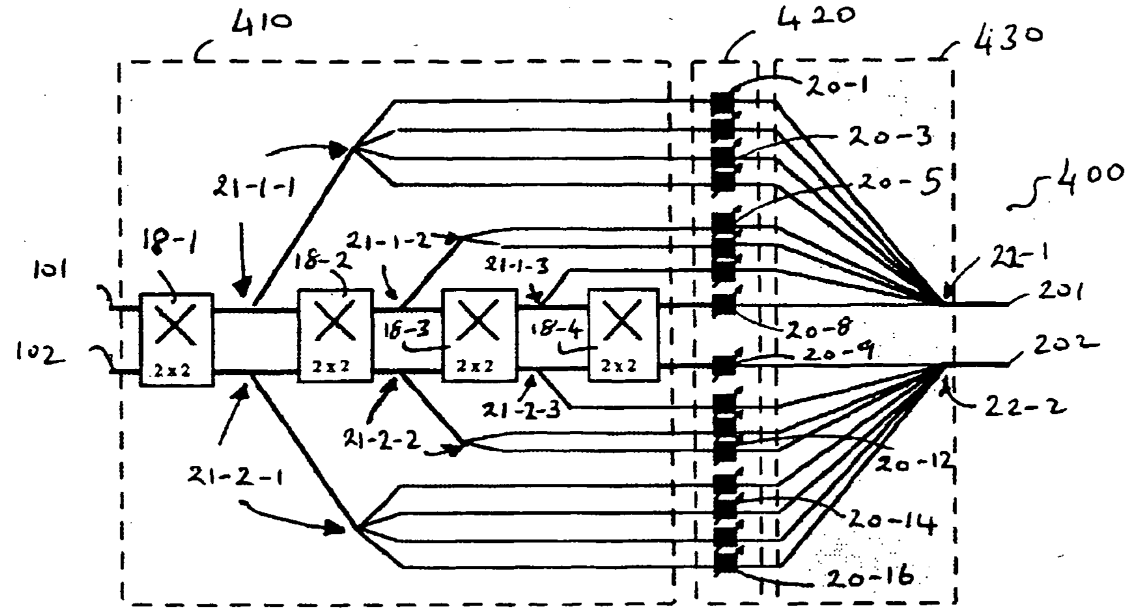


Fig. 6

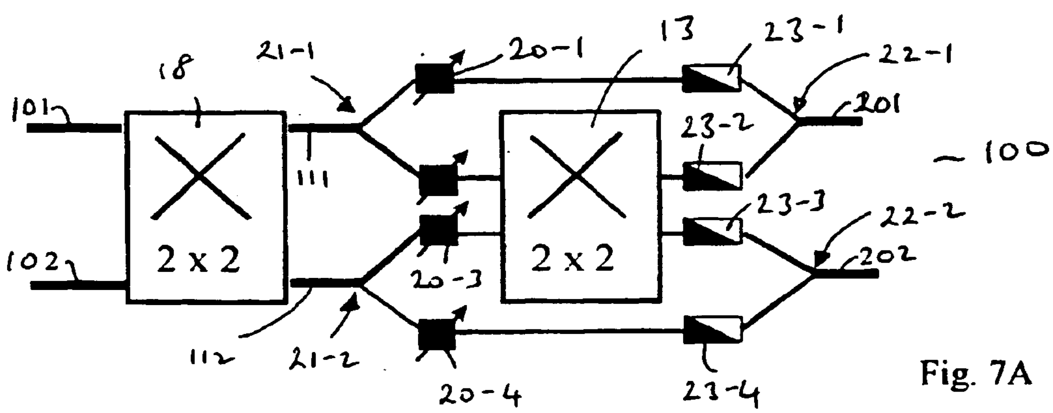


Fig. 7A

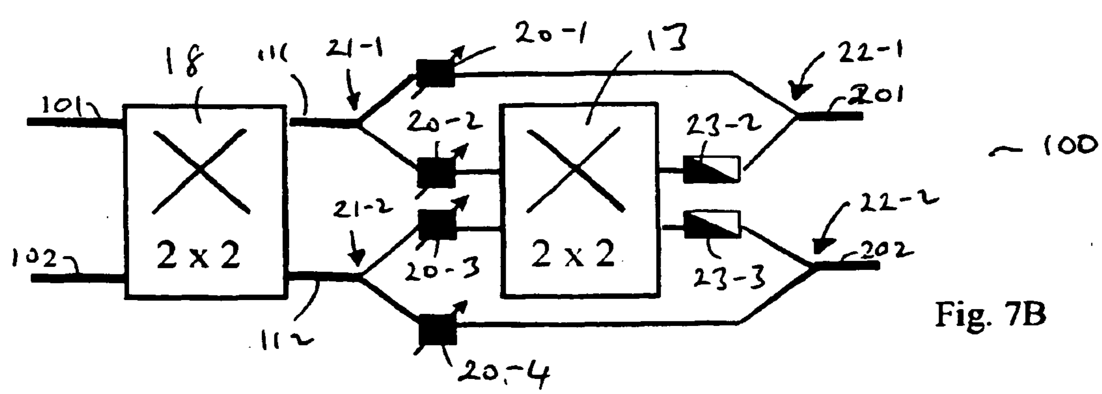


Fig. 7B

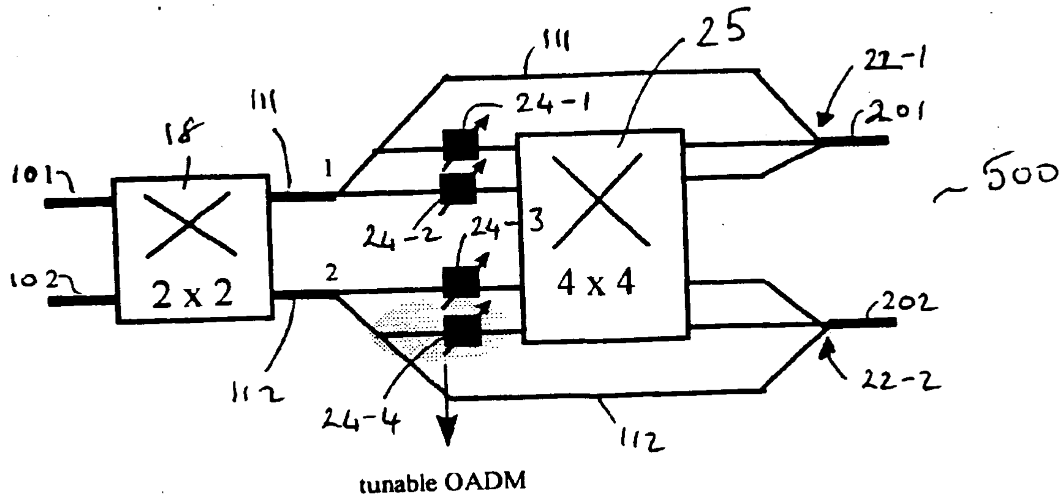
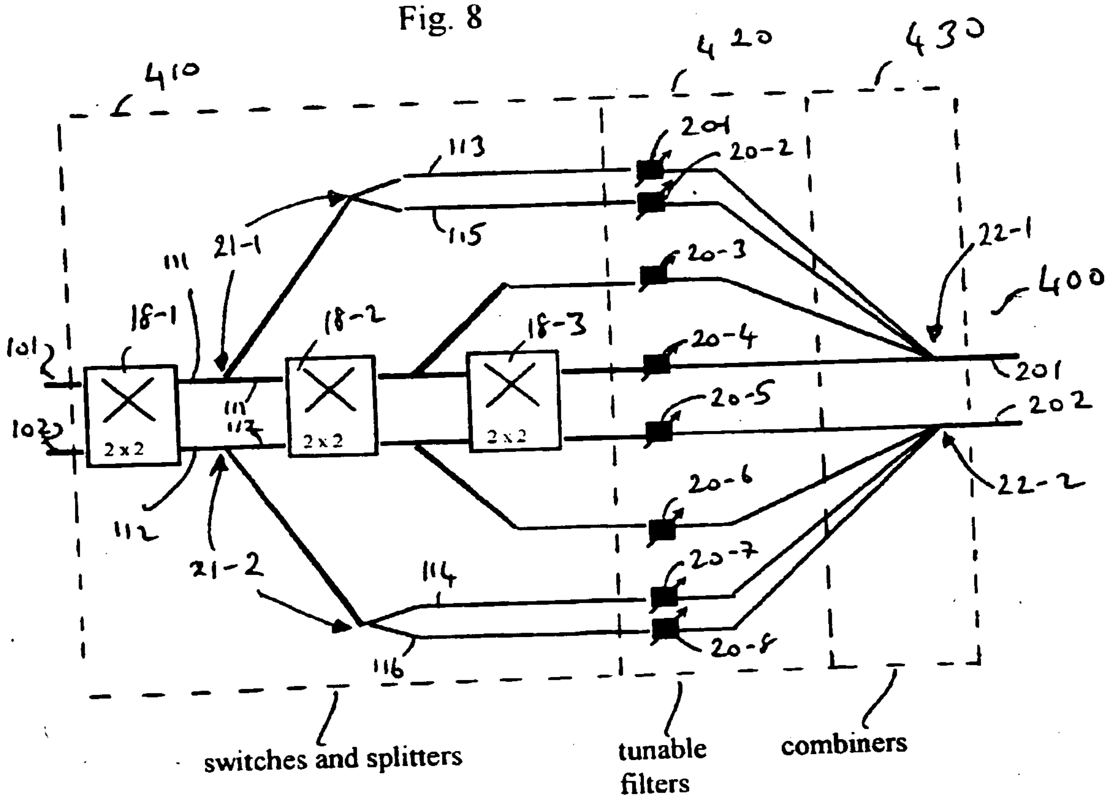

25
22-1
201
111
24-1
18
111
101
1
500
24-2
24-3
2
102
2 x 2
4 x 4
202
112
24-4
22-2
112
tunable OADM

Fig. 8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201
111
112
20-5
202
102
2x2
2x2
2x2
112
20-6
22-2
21-2
114
20-7
116
20-8
switches and splitters
tunable filters
combiners

Fig. 9A

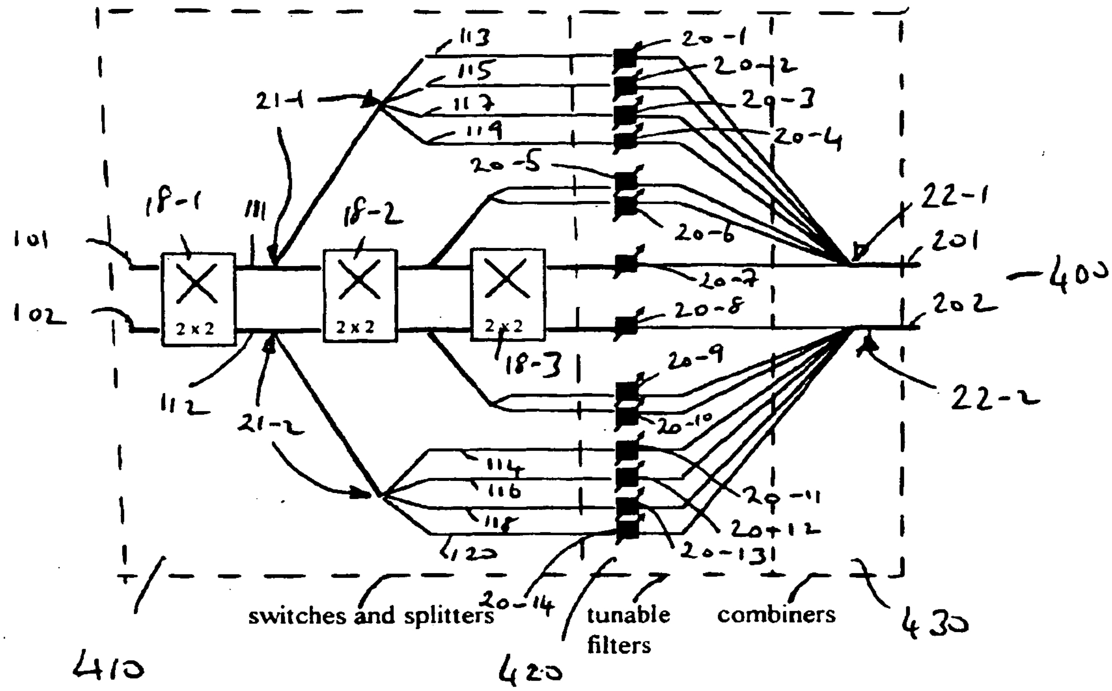


Fig. 9B

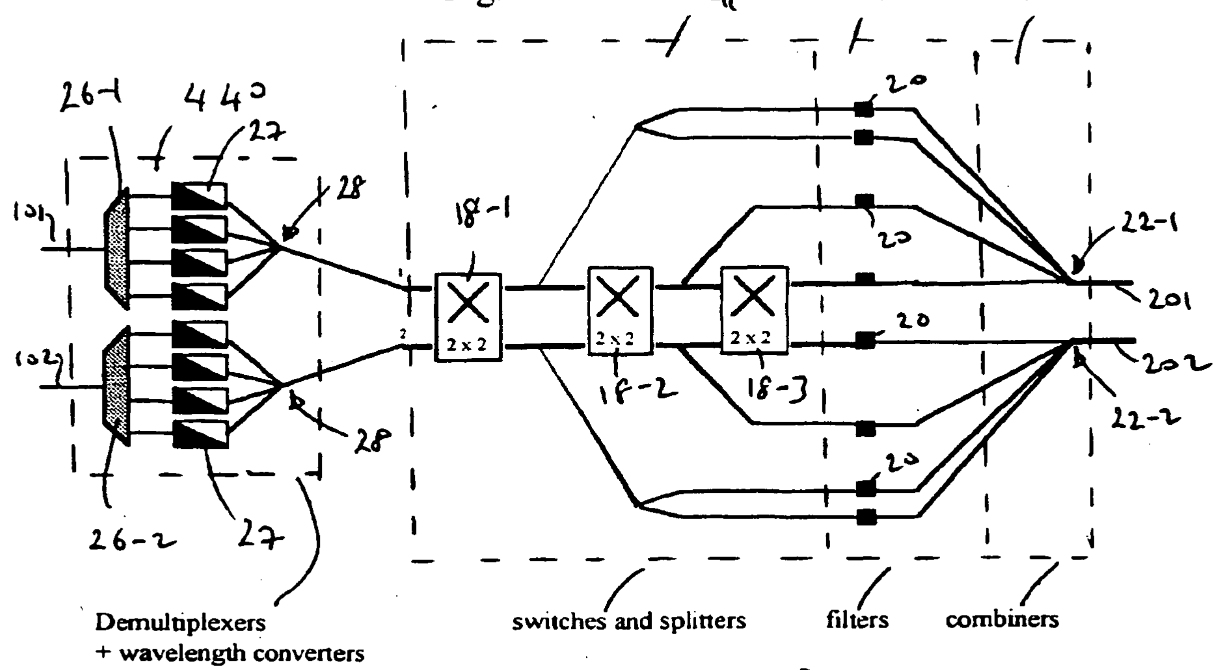
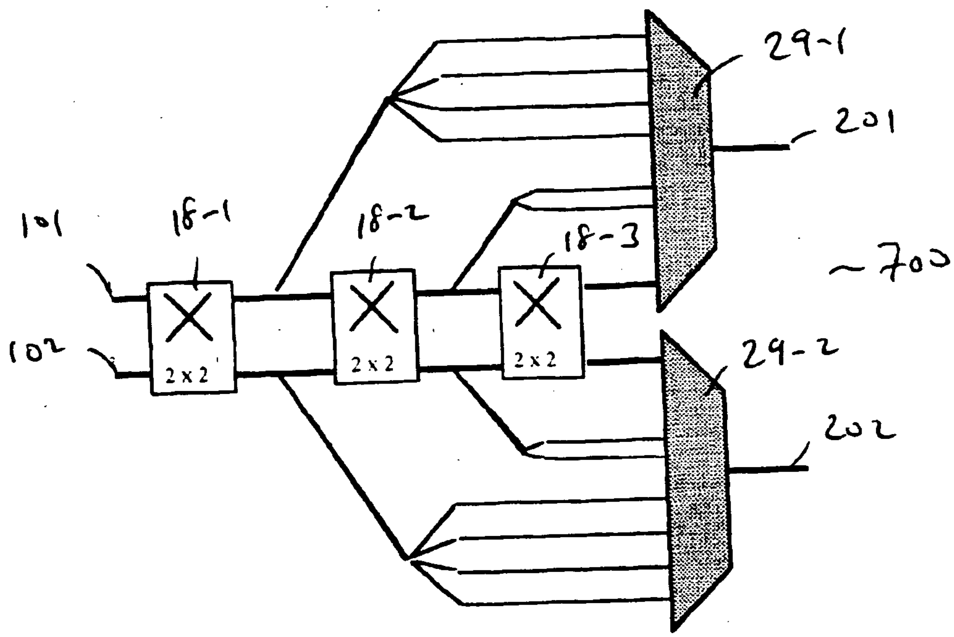


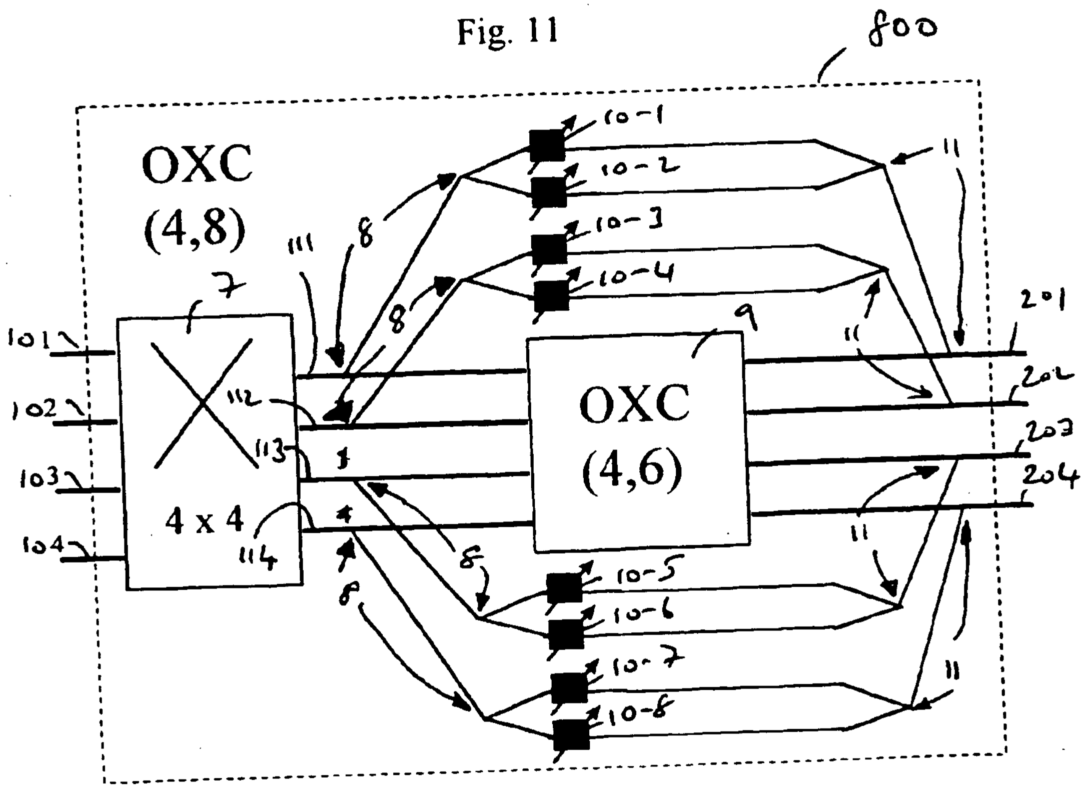
Fig. 10

600



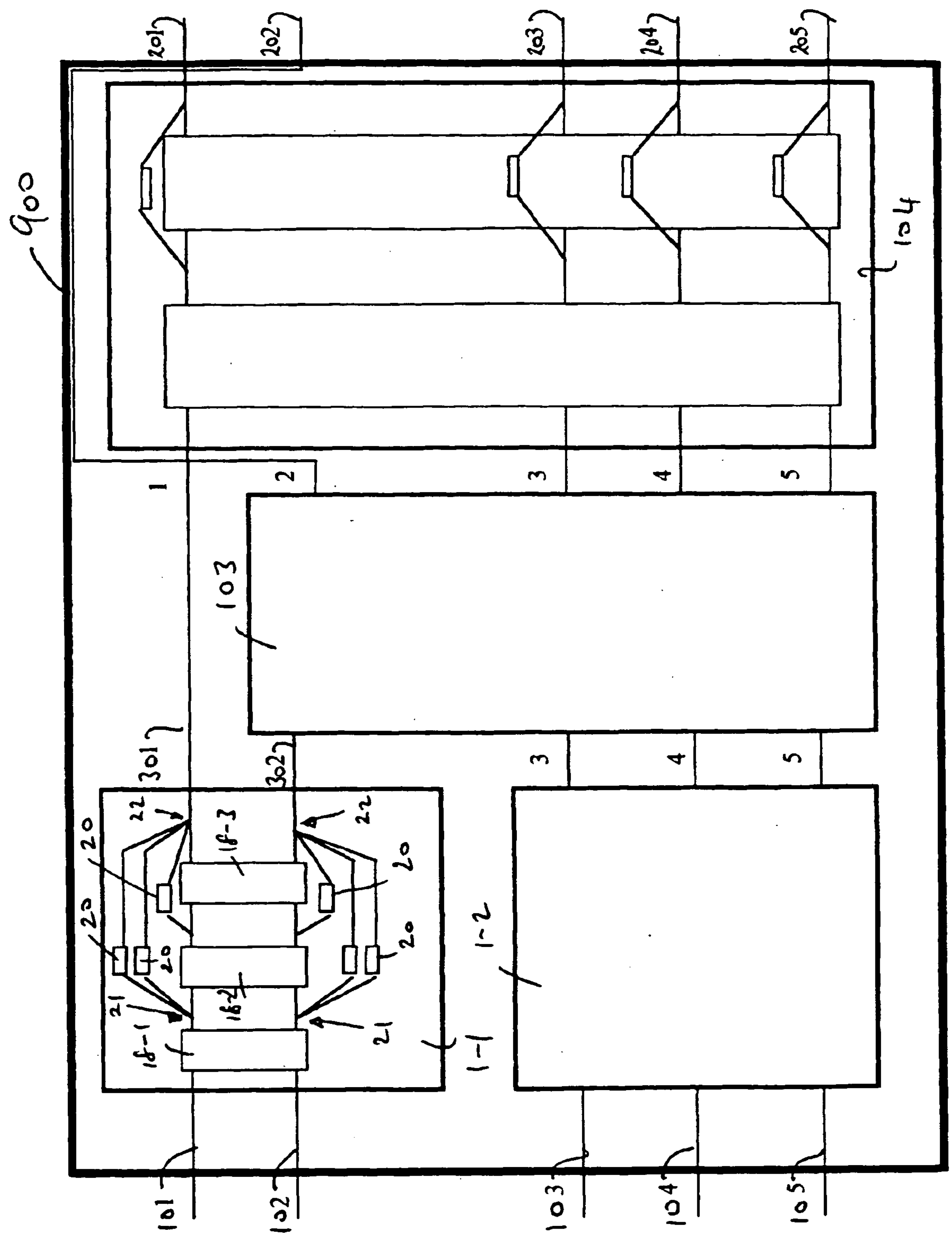
29-1
201
101
18-1
18-2
18-3
700
102
2 x 2
2 x 2
2 x 2
29-2
202
switches and splitters
multiplexers

Fig. 11



800
OXC
(4,8)
10-1
10-2
11
10-3
10-4
111
8
7
201
9
101
102
103
104
112
113
114
4 x 4
OXC
(4,6)
202
203
204
10-5
10-6
10-7
10-8

Fig. 12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4
5
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301
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18-1
21
1-1
1-2
101
102
103
104
105

Fig. 13

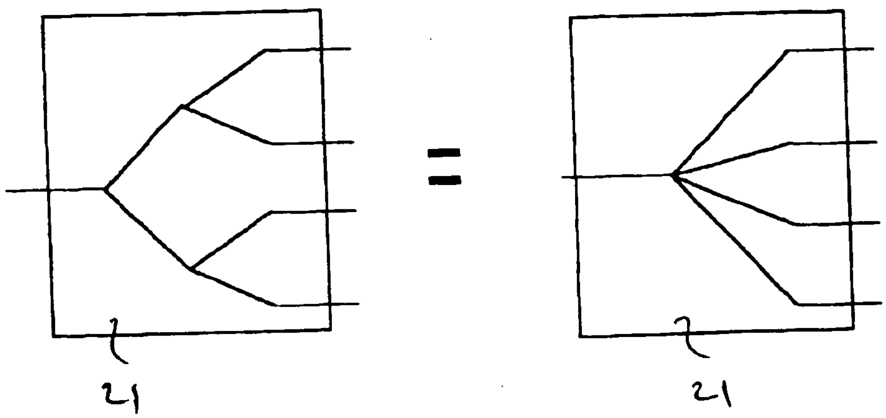
21
21

Fig. 14

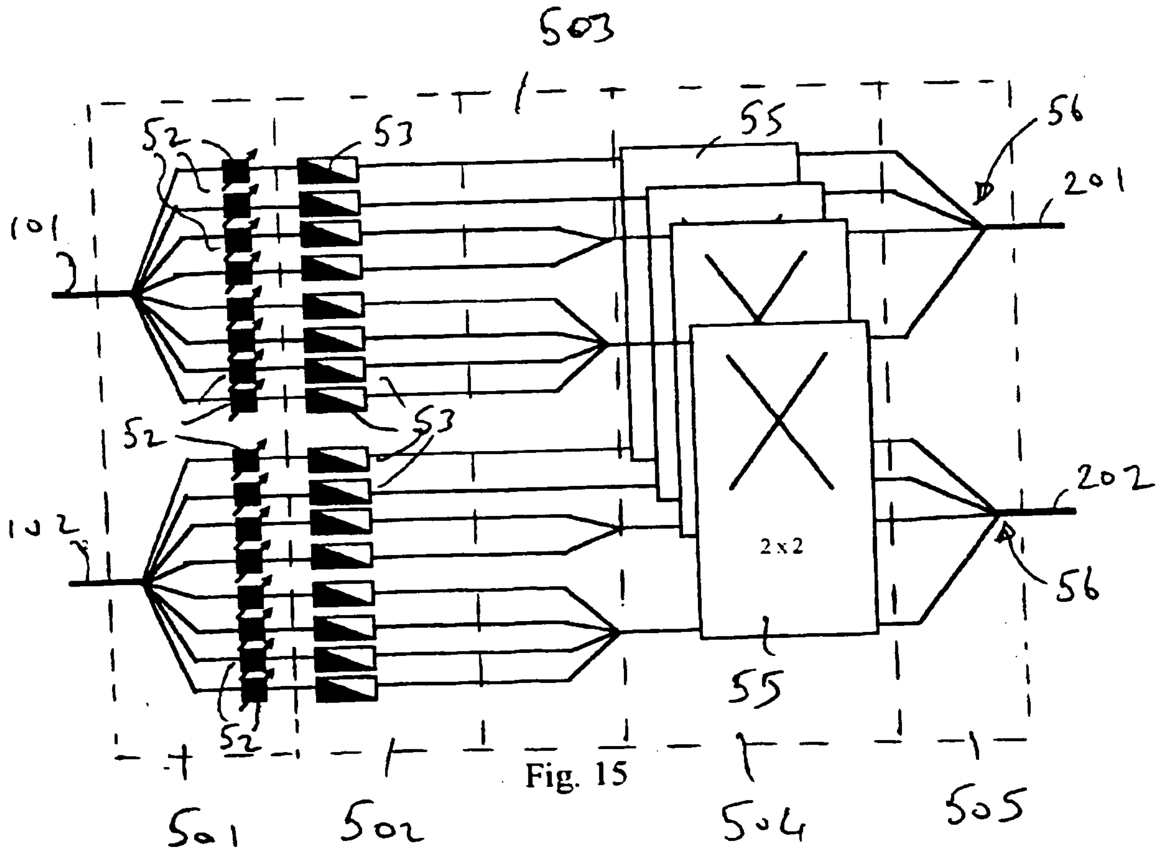
503
52
53
55
56
201
101
52
53
102
202
2x2
56
55
52
501
502
504
505

Fig. 15

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 99 20 0252

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION
X A	EP 0 838 918 A (ALSTHOM CGE ALCATEL) 29 April 1998 (1998-04-29) * figures 1,3,5 * * column 3, line 1-33 * * column 3, line 53 - column 4, line 47 *	1,3,6-8, 12,13,15 10	H04J14/02 H04Q11/00
A	EDWARDS H G: "OPTICAL NETWORK TESTBED MOVES WDM INTO THE FIELD" LASER FOCUS WORLD, vol. 32, no. 9, 1 September 1996 (1996-09-01), pages 129-132, 134, XP000629572 ISSN: 0740-2511 * figure 2 *	8	

TECHNICAL FIELDS SEARCHED

H04Q
H04J

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	22 July 1999	Dhondt, E

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO.

EP 99 20 0252

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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22-07-1999

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0838918 A	29-04-1998	FR 2755253 A JP 10153721 A	30-04-1998 09-06-1998

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

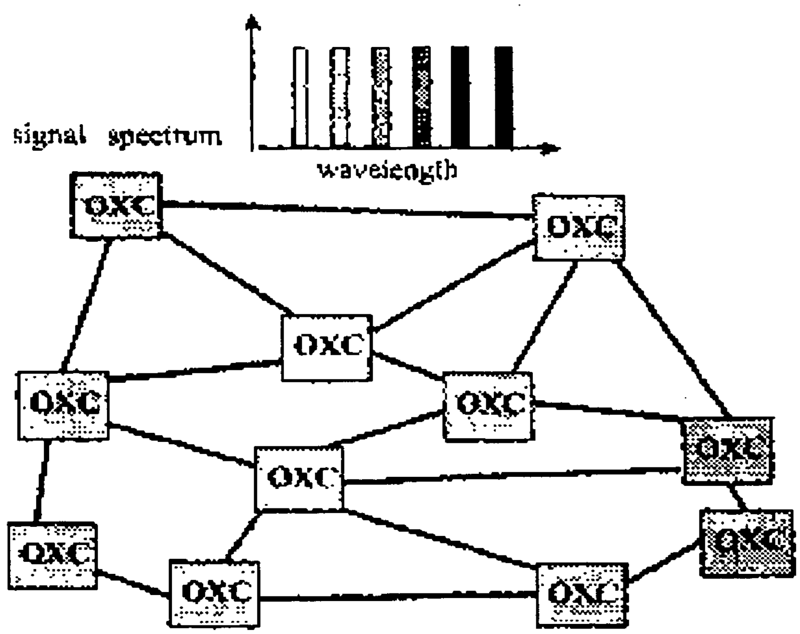

signal spectrum
wavelength
OXC
OXC
OXC
OXC
OXC
OXC
OXC
OXC
OXC
OXC
OXC
OXC

Fig. 1

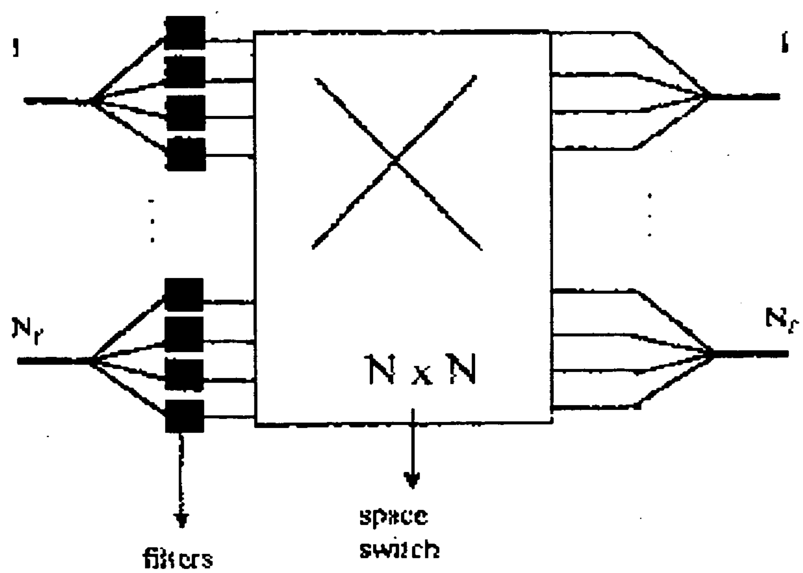

1
1
N_f
N_f
N x N
filters
space switch

Fig. 2A

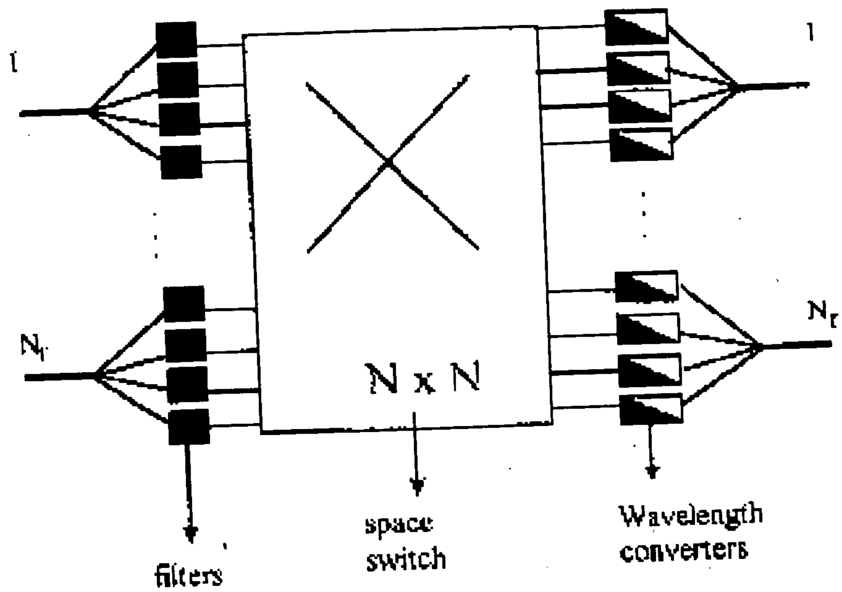

1
N x N
1
filters
space
switch
Wavelength
converters

Fig. 2B

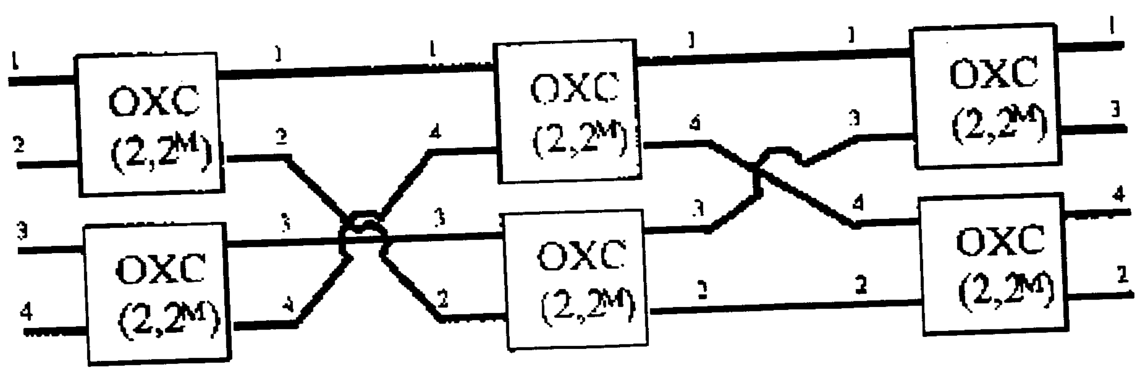

OXC
(2,2M)
OXC
(2,2M)
OXC
(2,2M)
OXC
(2,2M)
OXC
(2,2M)
OXC
(2,2M)

Fig. 3

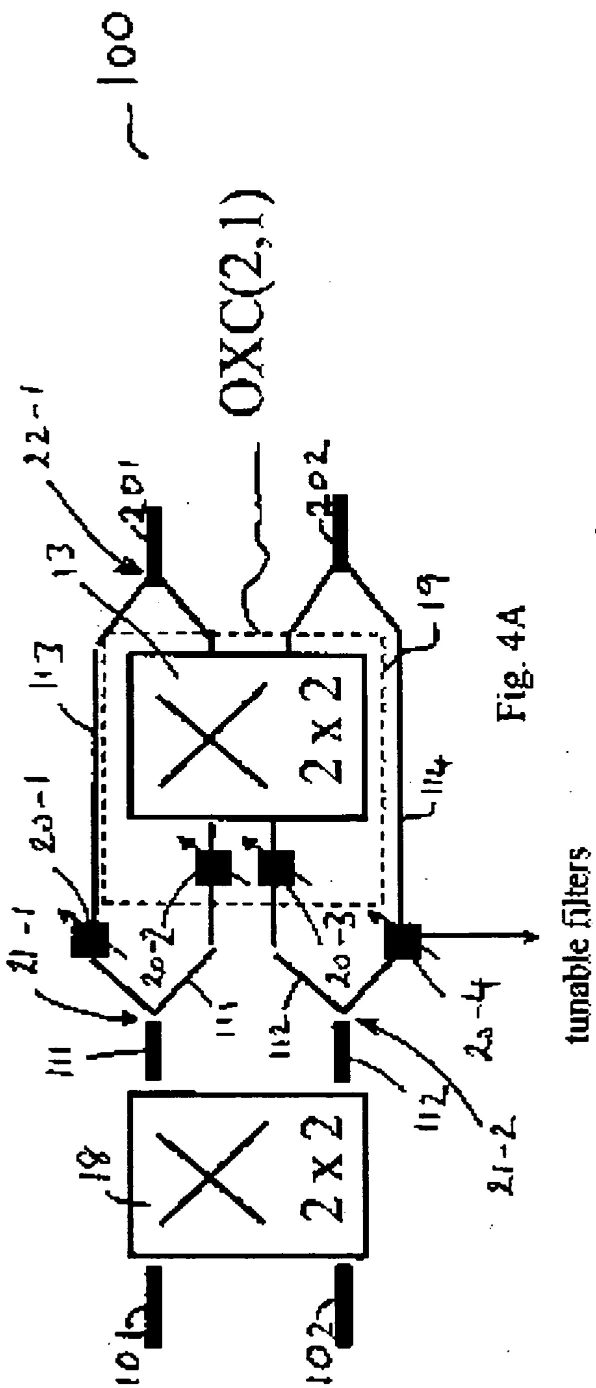

100
OXC(2,1)
2 x 2
2 x 2
tunable filters
101
102
111
112
113
114
13
18
19
201
202
20-2
20-3
20-4
21-1
21-2
22-1

Fig. 4A

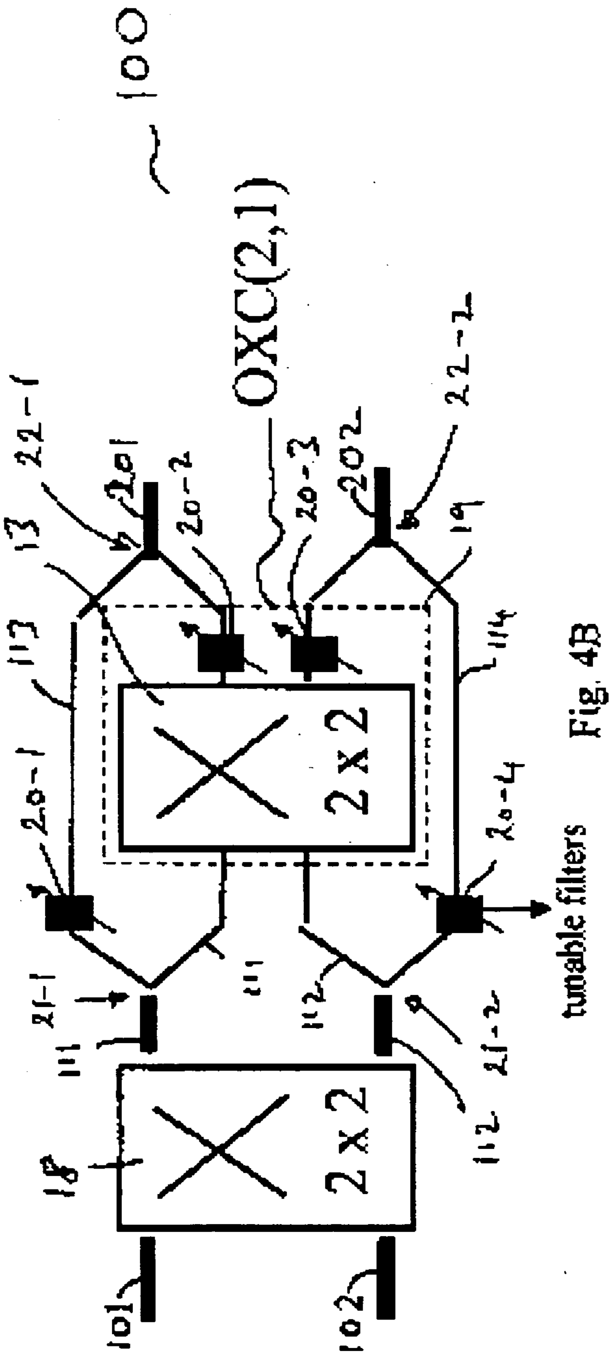

100
OXC(2,1)
2 x 2
2 x 2
tunable filters
101
102
111
112
113
114
13
18
19
201
202
20-1
20-2
20-3
20-4
21-1
21-2
22-1
22-2

Fig. 4B

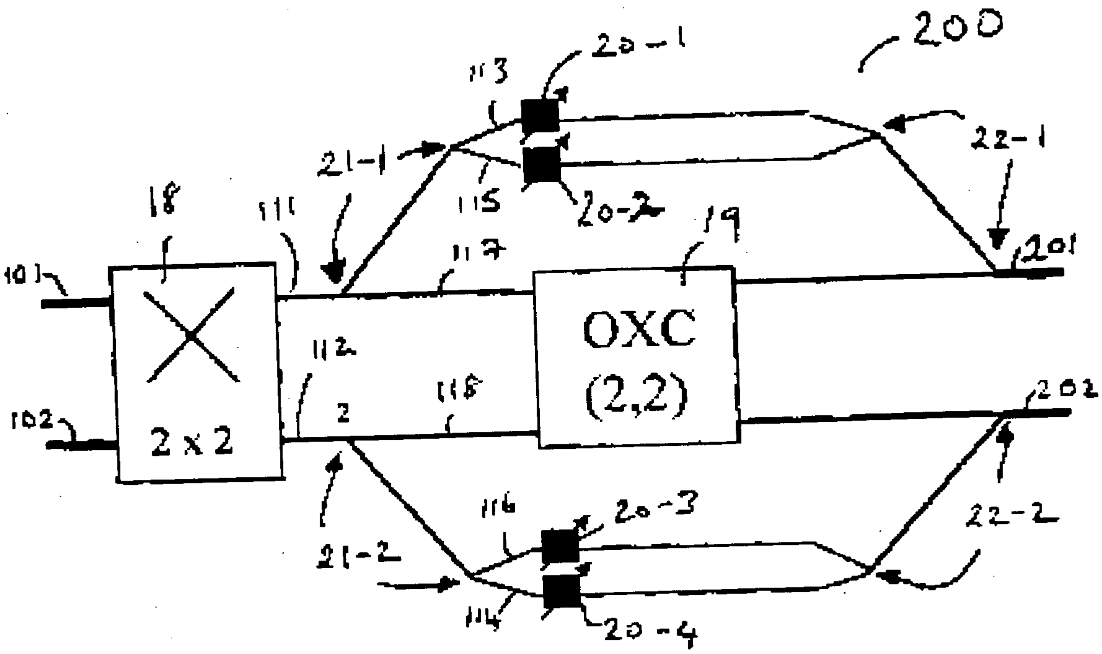

200
20-1
113
21-1
22-1
115
20-2
18
111
117
19
201
101
OXC
(2,2)
112
118
202
102
2
2 x 2
21-2
116
20-3
22-2
114
20-4

Fig. 5A

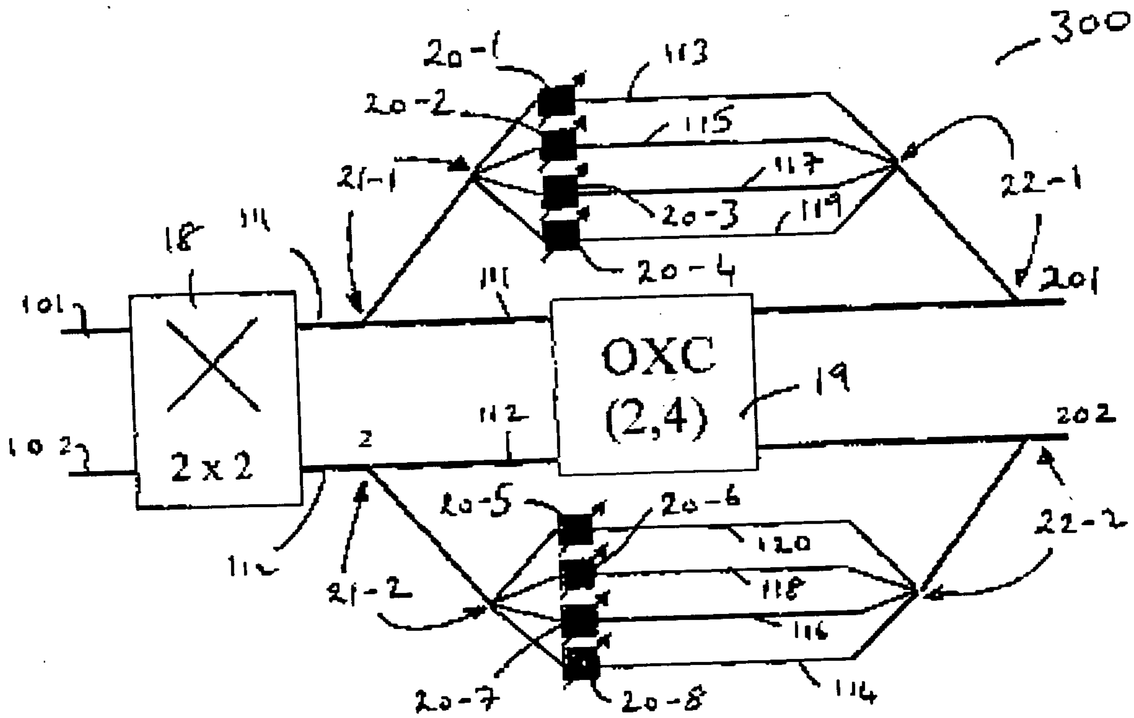

300
20-1
113
20-2
115
21-1
117
22-1
20-3
119
18
111
20-4
201
101
111
OXC
(2,4)
19
112
202
102
2
2 x 2
20-5
20-6
120
112
21-2
118
116
114
20-7
20-8

Fig. 5B

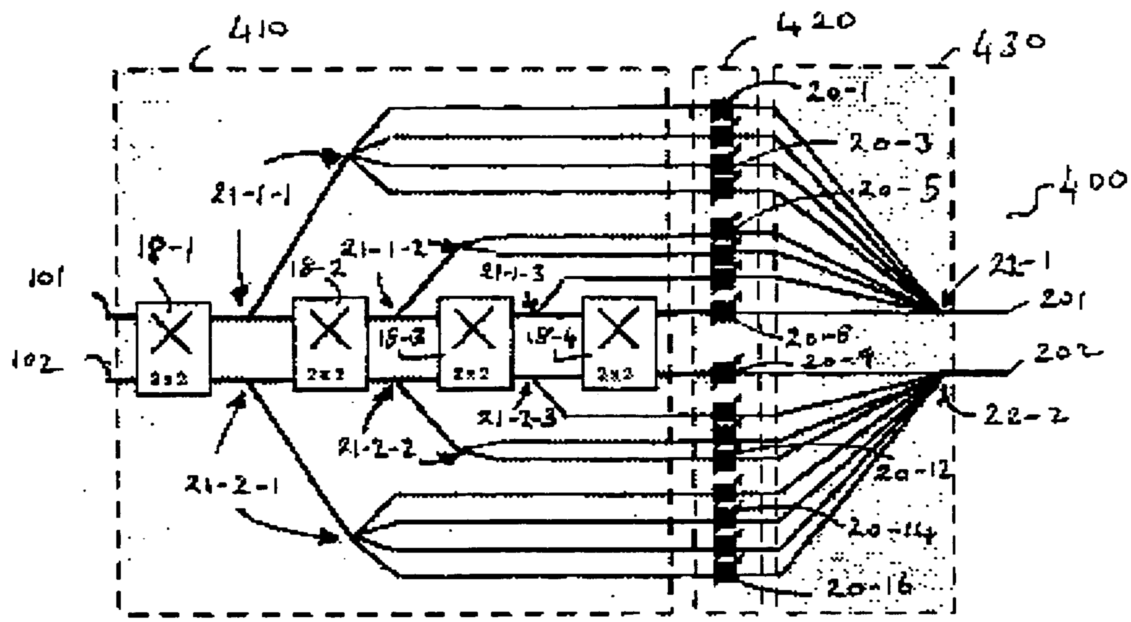


Fig. 6

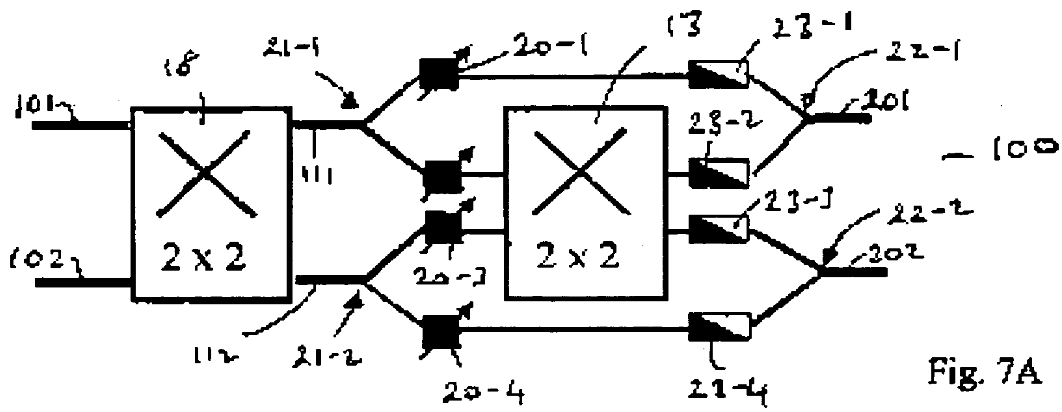


Fig. 7A

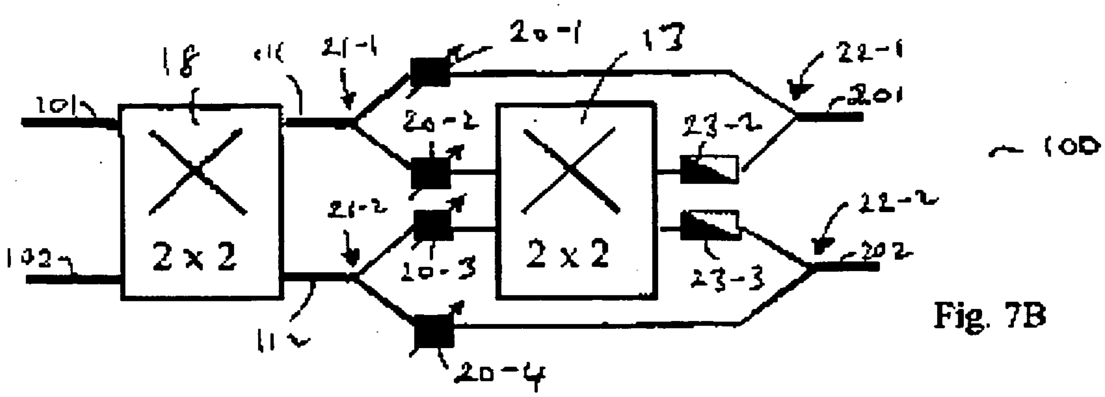
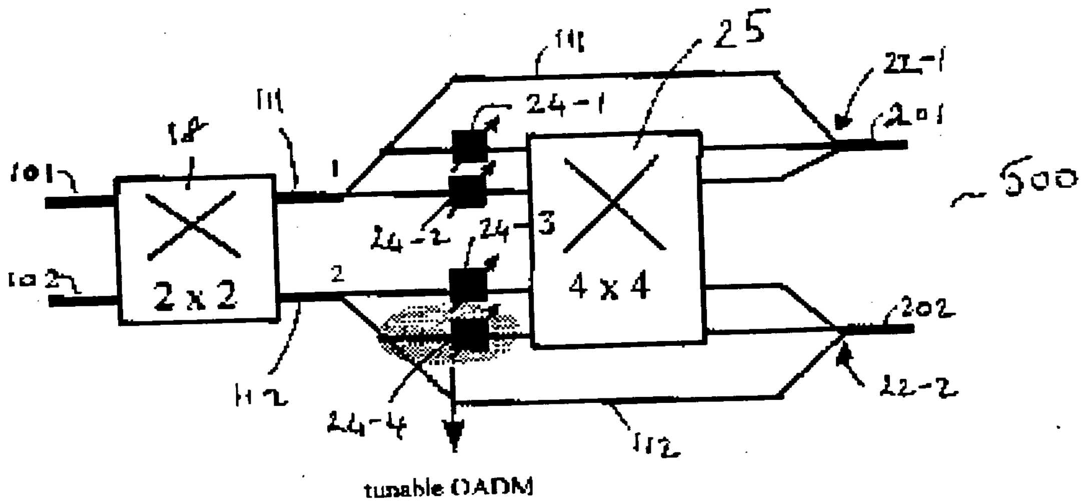
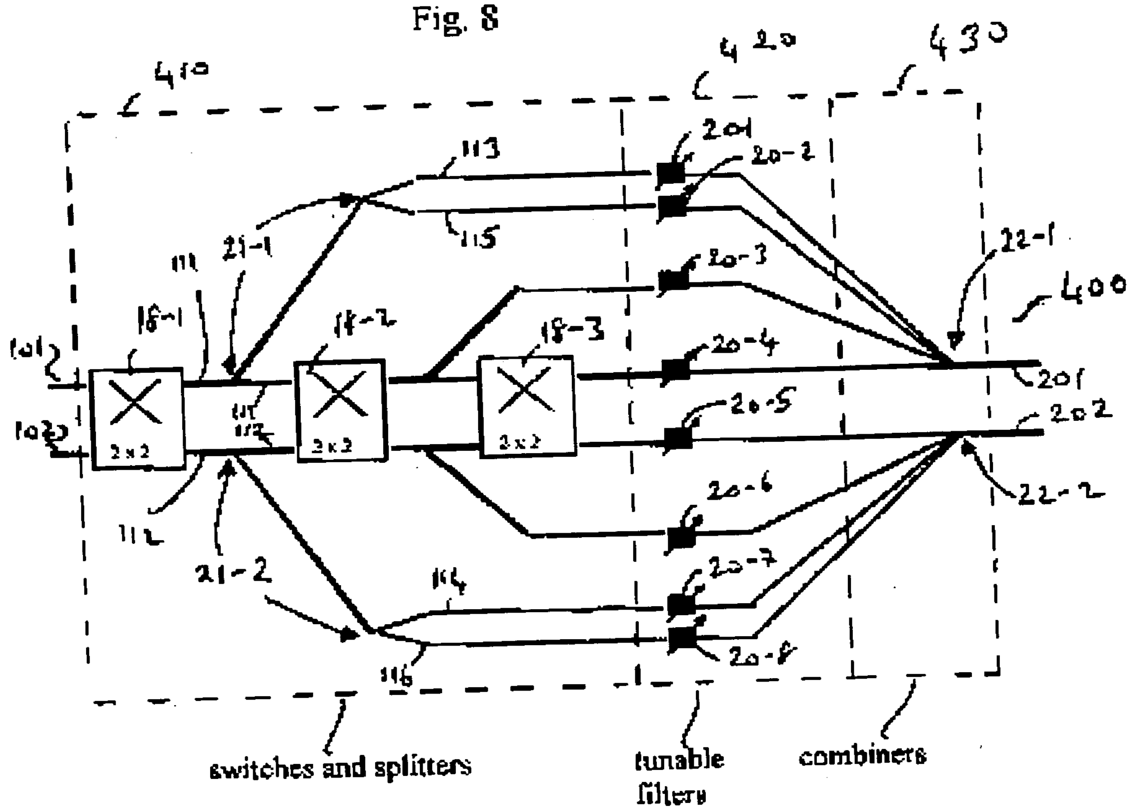


Fig. 7B



25
27-1
201
500
24-1
24-2
24-3
2x2
4x4
202
22-2
24-4
tunable OADM

Fig. 8



410
420
430
400
22-1
22-2
201
202
switches and splitters
tunable filters
combiners

Fig. 9A

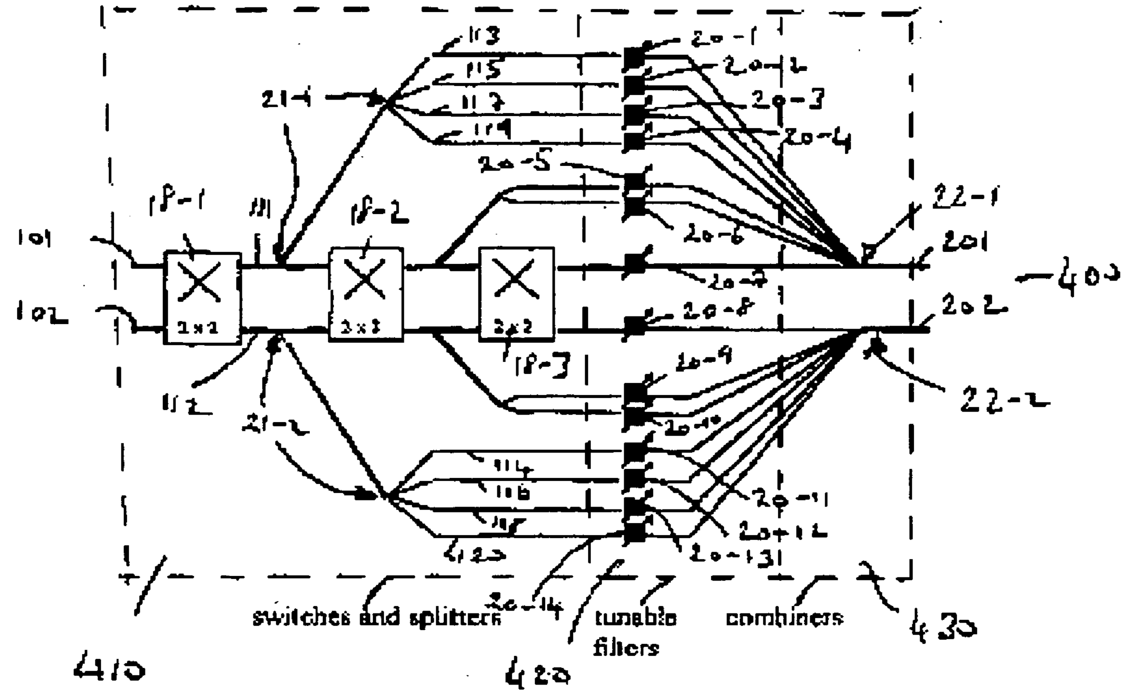

switches and splitters
tunable filters
combiners
2x2
2x2
2x2

Fig. 9B

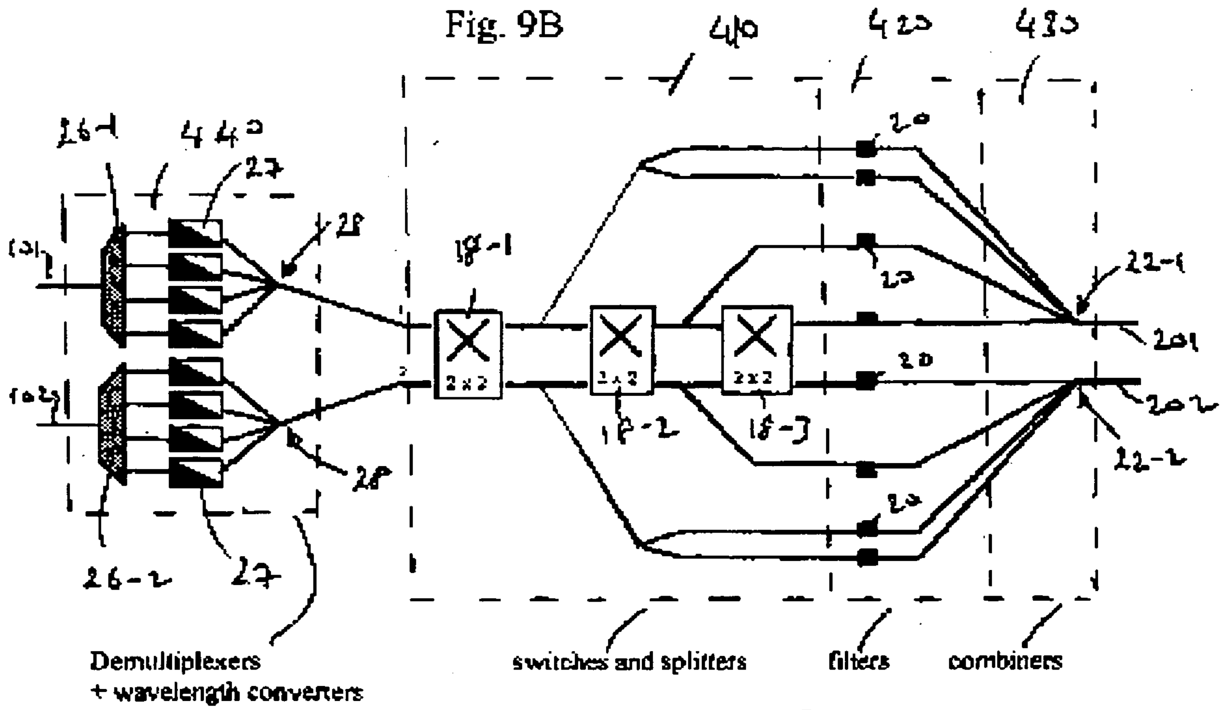
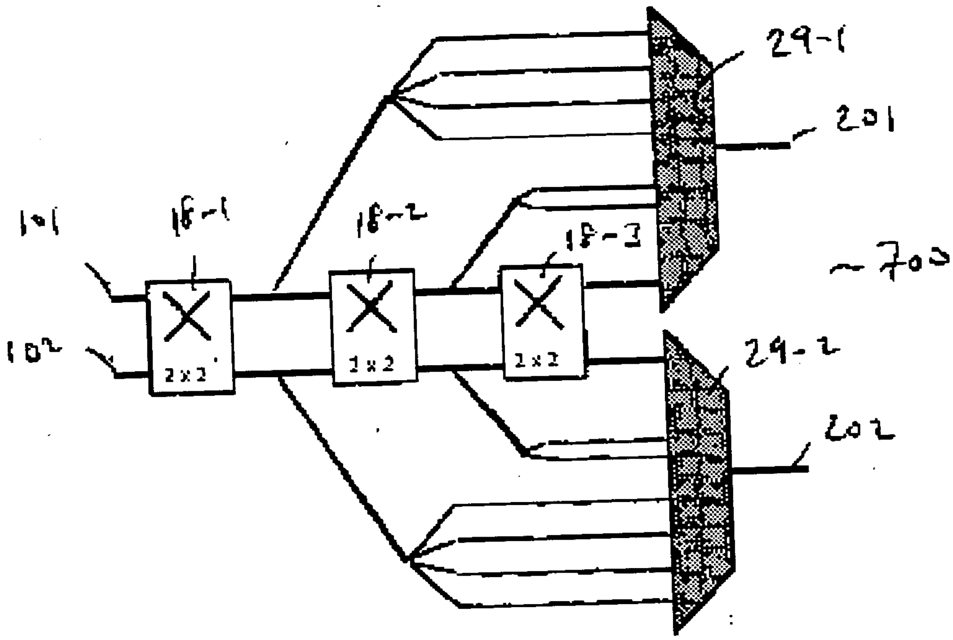

Demultiplexers
+ wavelength converters
switches and splitters
filters
combiners
2x2
2x2
2x2

Fig. 10



switches and splitters multiplexers

Fig. 11

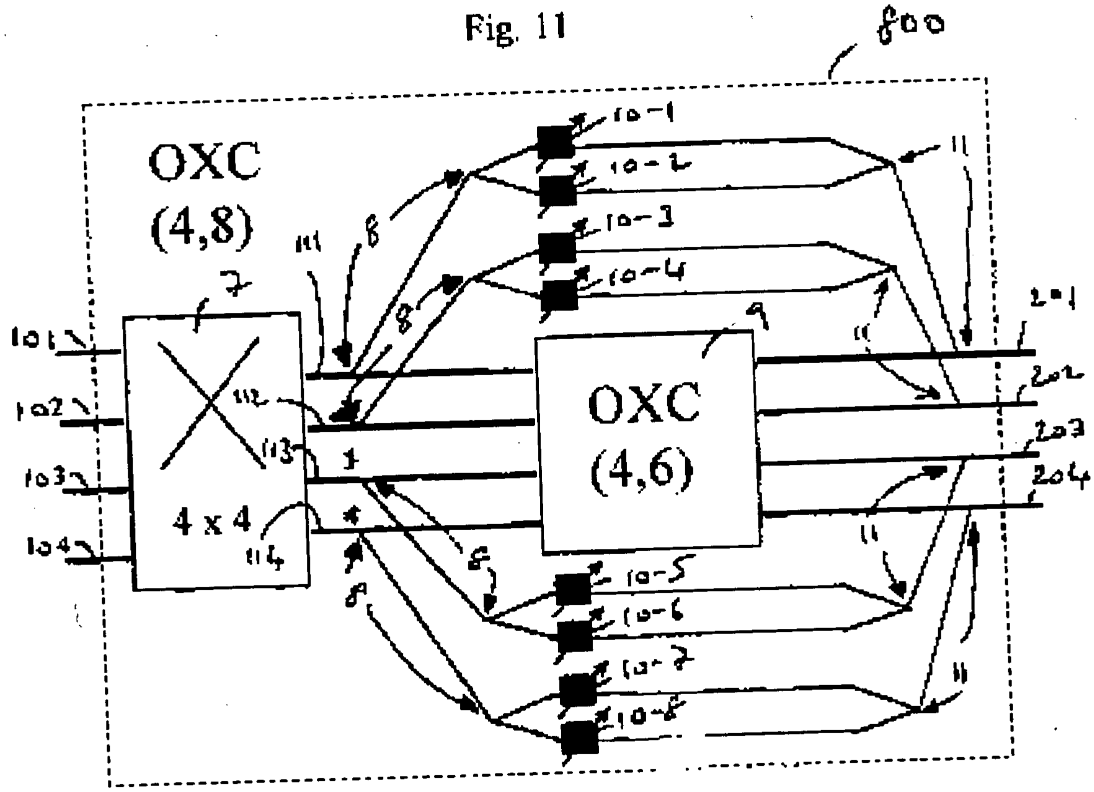


Fig. 12

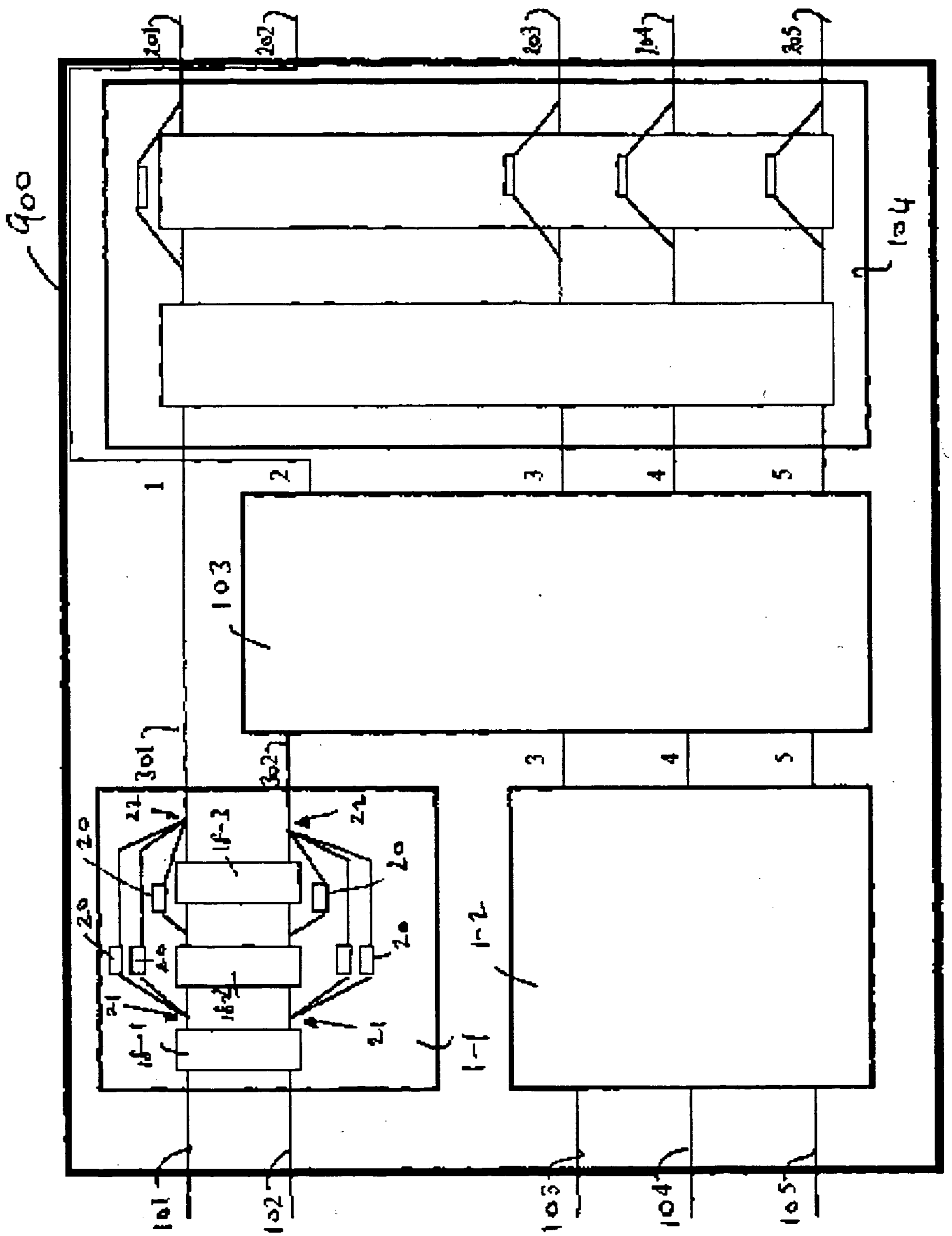

900
103
104
1-1
1-2
101
102
103
104
105
201
202
203
204
205
301
302
1
2
3
4
5

Fig. 13

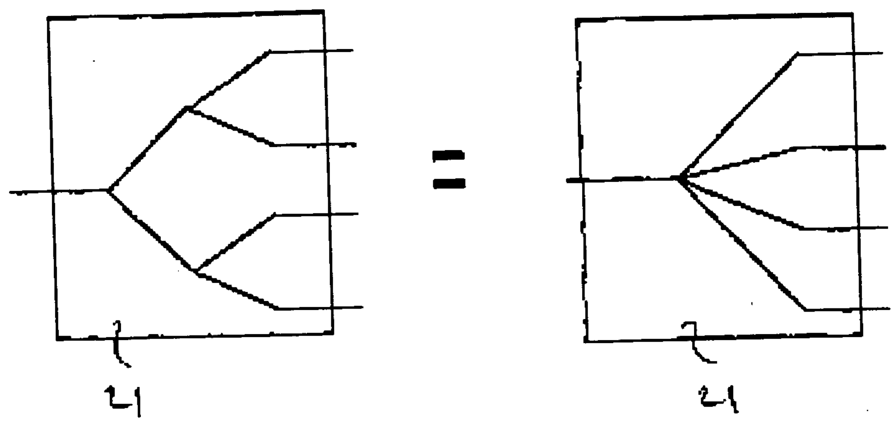

21
21

Fig. 14

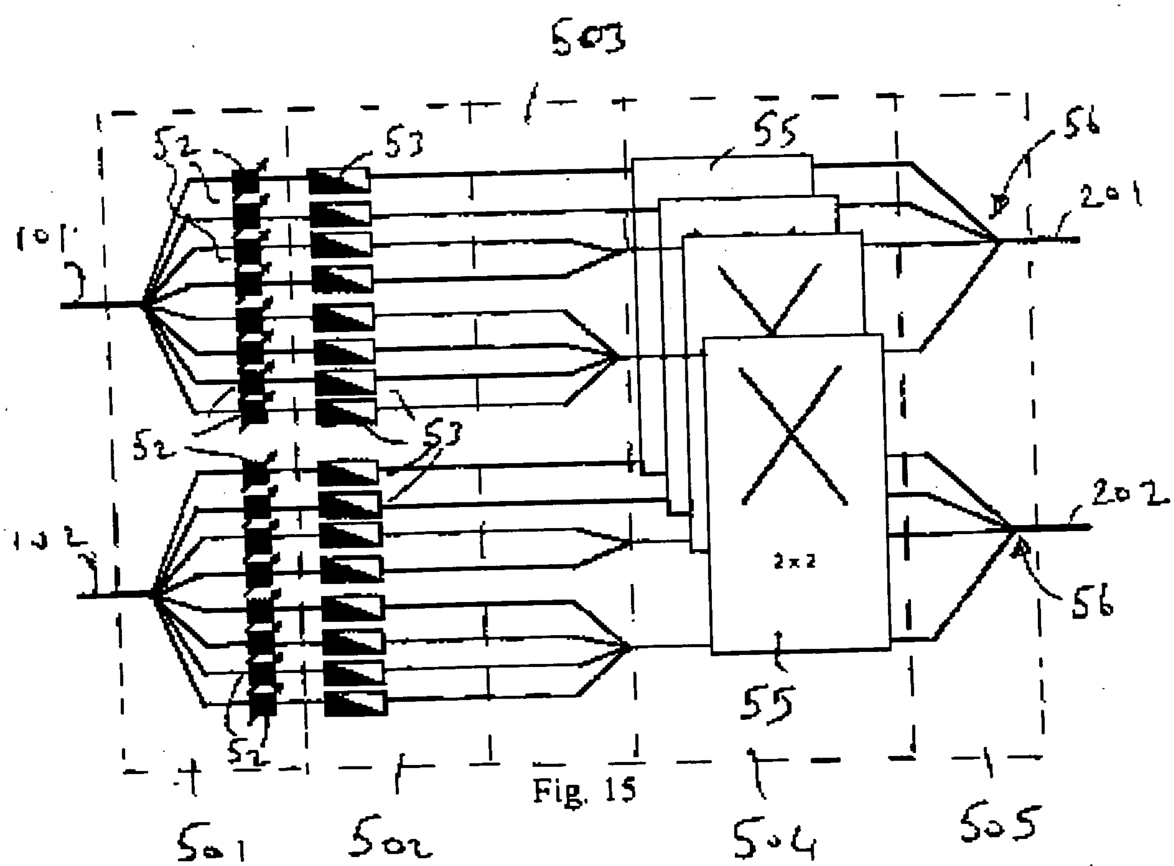

503
52
53
55
56
201
101
52
53
202
102
2x2
56
55
501
502
504
505

Fig. 15